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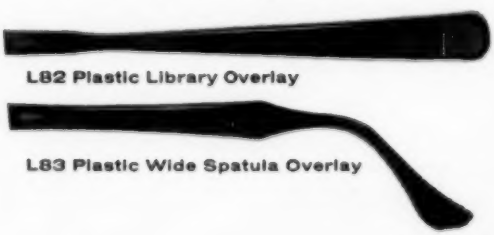

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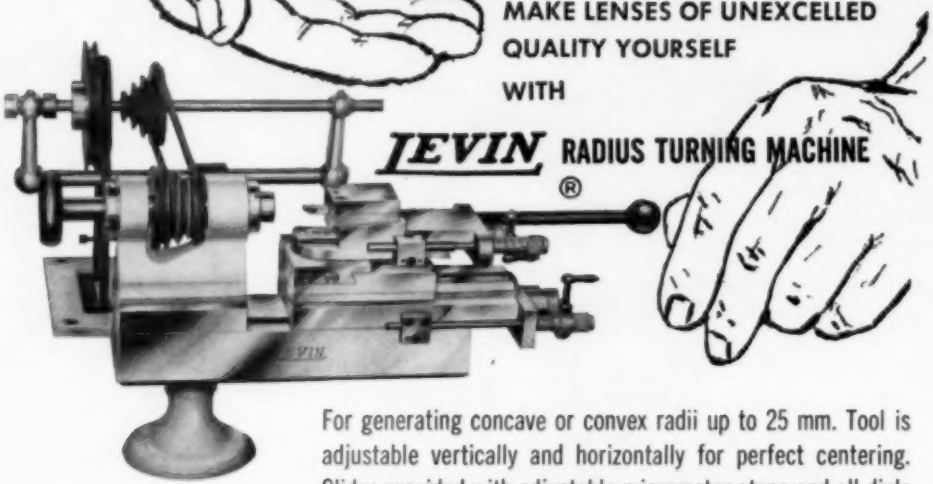

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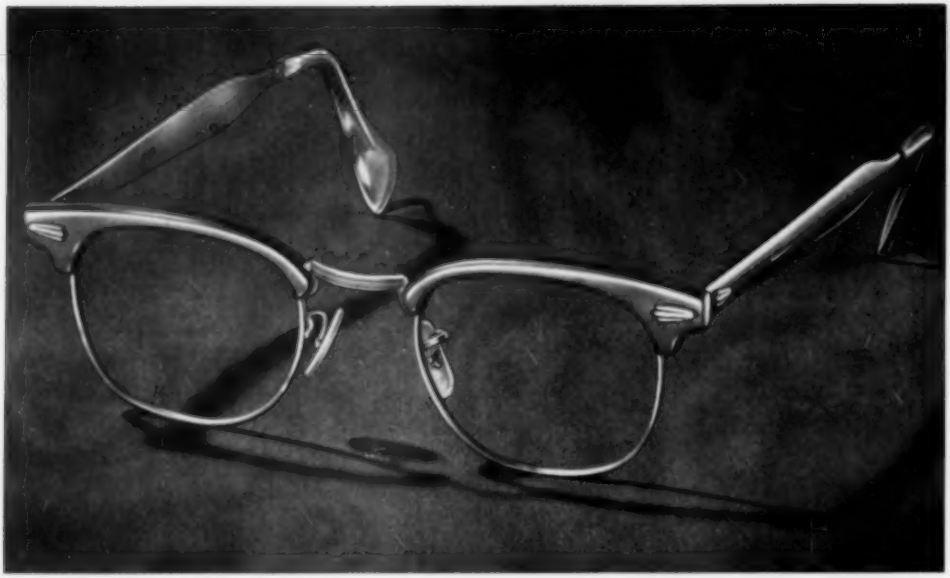

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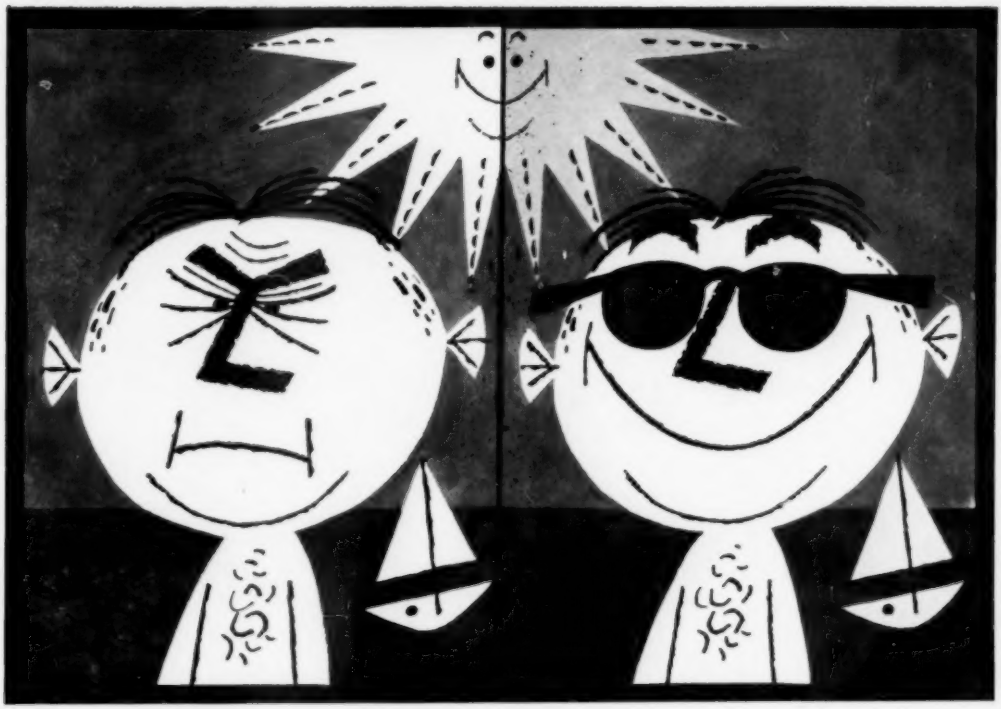

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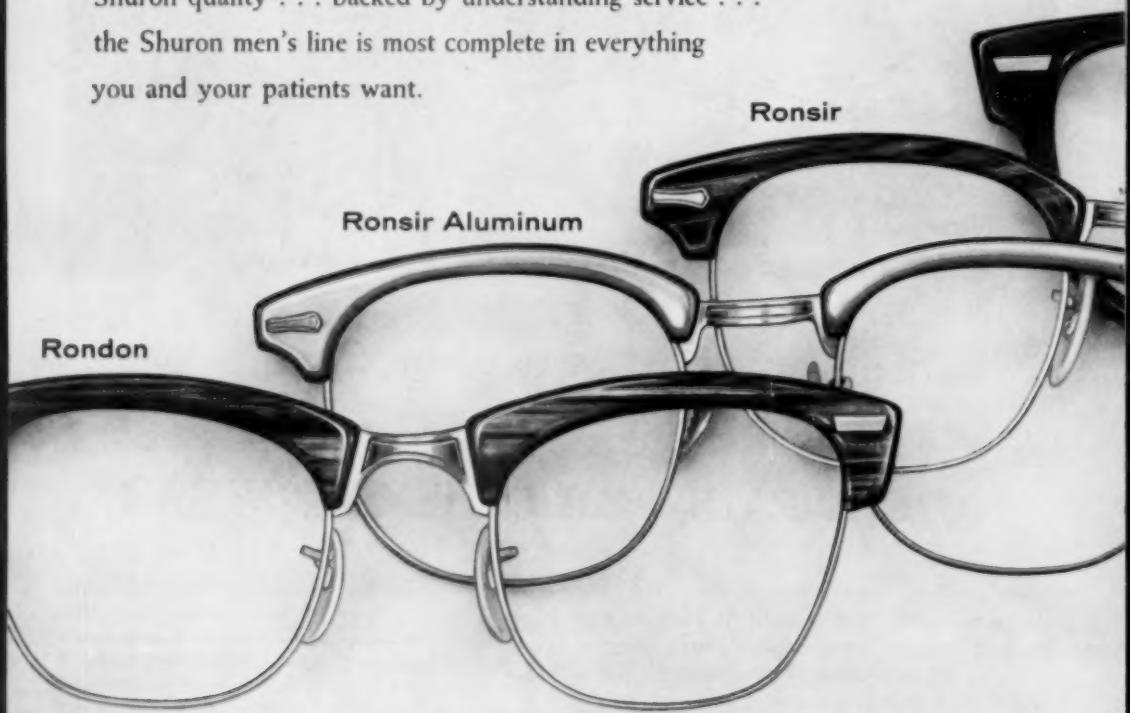

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PROBLEMS AND COMPROMISES IN THE DESIGN OF ASPHERIC CATARACT LENSES*

John K. Davis†
American Optical Company
Southbridge, Massachusetts

Wide field cataract lenses, aspheric and spherical, are not new. Approaches to the problem have been discussed at various times in the past.[1, 2, 3, 4, 5] Previous attempts have not yielded a light weight, economically feasible lens.

The aberrations chiefly responsible for the limited field of view in cataract lenses are curvature of field, astigmatism, and lateral color. The above references discuss all of these aberrations. Although lateral color is serious in cataract lenses, correcting it requires lenses with increased weight and bulk. This has resulted in negligible interest in such lenses, although their existence and possibilities have been known. The difficulty and expense involved in producing achromatic lenses, particularly in bifocal form, has further retarded interest in these lenses from a commercial standpoint.

The last few years have seen a development in the optical industry of fabricating processes which could reliably produce plastic lenses of high powers. At the same time, for military and instrument applications, methods have been developed for producing aspheric glass surfaces of steep curvatures in limited quantities and at relatively high cost. It became evident, however, that by using such relatively expensive surfaces as glass molds, strongly curved plastic aspheric lenses could be produced reliably and at a practical cost.

This paper deals with the problems and compromises necessary to design an aspheric cataract lens series. The problems can be divided into two classifications, the first being the optical or functional performance of the lens. The goal is to provide as good vision as possible. The moving eye and the lens is considered as an instrument whose function is to provide a sharp, undistorted picture on the retina, for all

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†A.B., Head, Ophthalmic Lens Section, New Product Development Department, Fellow, American Academy of Optometry.

directions of gaze. If the second part of the problem were disregarded, the first part could be easily solved. Doublets, or multi-element lenses, made from rare or unstable optical materials might be used. Heavy, bulky lenses would enable the designer to provide an ideal image for the patient with the most unusual prescription.

The second type of problem, however, is to get a lens of reasonable weight and bulk, attractive in appearance, which would lend itself to easy fitting in a conventional frame, and be of a material which is reasonably stable and permanent. There must be a practical means of providing a bifocal segment.

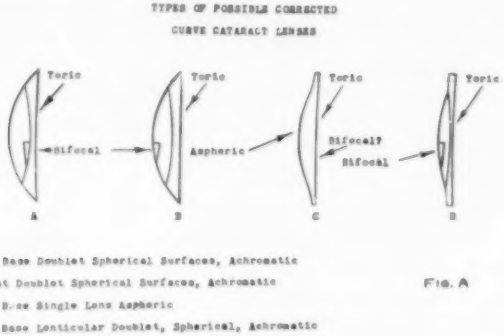


FIG. A

Figure A illustrates several solutions to the problem, all of which lend themselves to fitting into conventional frames. It can be seen that Lens "C," a one-piece aspheric, or Lens "D," a *doublet* spherical type, would be lighter in weight, less bulky, and more easily fitted than either "A" or "B." Lens "C" is shown as a blended lenticular lens, that is, the sharp borderline between the optical portion and the carrier portion has been blended into a smooth curve to remove the sharp demarcation zone.

Actual experiments, however, prove that to obtain equivalent optical fields of view between a blended lenticular and a nonblended lenticular, the blended lenticular had to be increased in thickness to an extent where the increased bulk and weight seemed to offset the advantage obtained by removing the sharp borderline. Further, if the sharp borderline were made of a diameter approximately equal to most frames, it would tend to blend into the frame, or, actually, lie within the frame groove, so that it would be either invisible, or not noticeably unattractive. As a result of these experiments and computations, it was decided that this design would be of a conventional lenticular type, with a 40 mm.

spot. This would provide as wide a field as can be used by most patients, and would fit fashionable frames without presenting thick edges or increasing thickness. The choice of a relatively hard plastic material makes it practical to provide a one-piece bifocal segment on the front surface and a desirable reduction in weight.

The functional or performance problems may now be considered. The objective in this respect is to provide a lens which does for aphakic patients what corrected curve lenses do for ordinary myopes and hypermetropes. Figure B illustrates the problem. A noncorrected positive

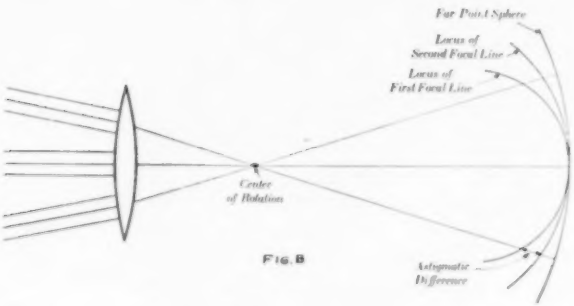


FIG. B

spectacle lens has its tangential focus, for off-axis points, nearer the lens than its sagittal focus. In the diagram, these are the circles labeled "Locus of first focal line," and "Locus of second focal line." The far point sphere falls back of either of these two lines. The problem is further complicated by the fact that a different situation exists for each point of the toric; that is, in a sense, we have to design two lenses in one. One which will correct along the axis of the cylinder and one in the cylinder meridian.

This aspect of the problem may be neglected for now and only spherical prescriptions considered. Here, the problem is to maximize the acuity when we consider both the tangential and sagittal focus, and, lurking in the background as it were, is the factor of lateral color. Little can be done about this factor with a single piece of optical material. Keeping these factors in mind, let us devote our attention to aspheric surfaces, and what they can and cannot do.

In the upper diagram of Figure 1 are plots for two lenses, a —3.00 base sphere of 12.00 diopters and an aspheric. Solid lines indicate the change in tangential focus with the field of view, and the dotted lines indicate the change in sagittal focus. It is seen that the sphere is well corrected in the sagittal meridian, but extremely uncorrected in the

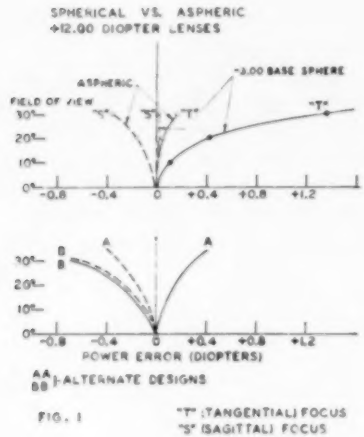


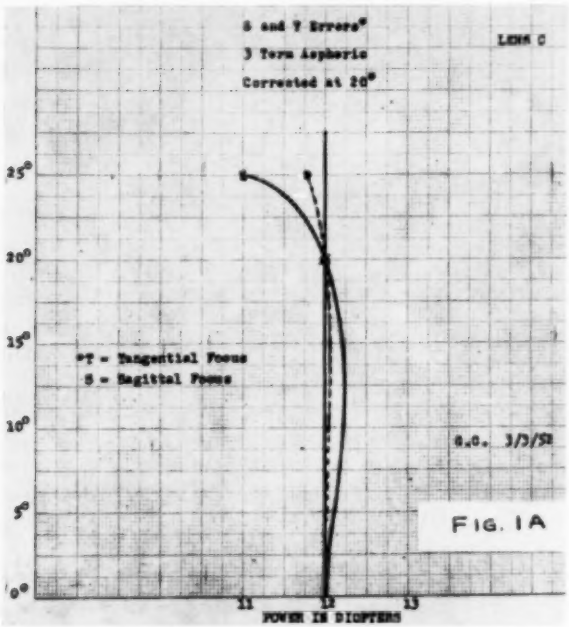
FIG. 1

tangential. The aspheric has some slight residual error in the tangential and more in the sagittal. By changing the shape of the aspheric surface, other designs, as illustrated in the lower diagram, are possible. BB indicates the plot of an aspheric lens, with practically no astigmatism, but appreciable power error for wide fields of view. Can these curves, BB, be made to straighten out and lie on the zero line?

Figure 1A illustrates an attempt to do that. At 20°, there is no astigmatism, and both curves lie on the zero line. There is a quarter diopter zone at 10°, and 1.00 D. of power and 0.75 D. of a diopter of astigmatism at 25°.

These three aspheric designs illustrate the restrictions on design which still exist, even when using an aspheric surface. This is inherent in a single continuous surface. The zonal powers or focus of an aspheric lens are functions of the curvature in each meridian at the point the ray bundle passes through the lens, just as they are functions of the curvatures on axis in any lens. The sagittal focus is a function of the curvature in one meridian; tangential focus is a function of the curvature in the other. The tangential curvature is a function of the derivative of the sagittal curve. If we set the tangential correction at two points in the field and the curve changes smoothly between these points, the sagittal correction is predetermined and the designer can do nothing about it. He is at the mercy of these mathematical relationships between sagittal and tangential curvatures.

Will changing base curves help? For a given prescription, the choice of base curves does effect these relationships in a minor way, but



computations indicate that the relationship between sagittal and tangential errors are not sensitive to base curve changes when the vertex power of the lens is held constant. A different aspheric is required, depending on base curve, but the final performance of the lens remains nearly the same. Since an ideal correction cannot be obtained, it is necessary to decide what sort of compromise is best.

The relative effects on image quality of tangential error, sagittal error, and lateral color have been studied.[1] Since lateral color is a tangential blur, it is reasoned that the destruction of useful information in the tangential meridian would be heightened by lateral color, and that tangential power error ought to be kept at a minimum. To do this, we have seen, requires that sagittal errors be increased. The question is—how far should one let the sagittal error go? To obtain quantitative information with respect to these additive effects, color photographs of a Snellen Chart were taken. The camera distance was 5 feet, the lens a 58 mm. at F/8. For various photographs, possible aspheric compromises were simulated with trial case lenses and a prism. A graph of relative acuity vs. type of aspheric compromise was plotted and is shown in Figure 2. It is seen that if we keep the tangential power error

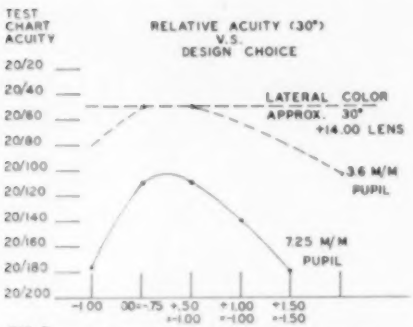


FIG. 2

to +0.50 D. and, if necessary, let the sagittal error go up to —0.75 D., we will be providing a lens which is nearly optimum in its performance. We now know what kind of a correction we want. We want a relatively flat field tangential correction. We know that it can vary within the limits as shown, without seriously affecting acuity.

Most cataract lenses are toric prescriptions, which means, in a sense, that each lens has to fill two different prescriptions and that each aspheric surface should be corrected for two different prescriptions: one at one point of the toric and one at the other. Since, by presently available techniques, we are limited to putting the aspheric surface on the symmetrical front surface of the lens, some compromise is necessary.

Further, in order to reduce magnification and the bulky appearance of the lenses, those who fit cataract prescriptions usually fit them as close to the eye as possible. Depending on facial contours and frame styles, there is a wide variation in this fitting distance. A lens that performs well at one fitting distance may or may not perform well at another. To determine what factors might be of help in these respects, a wide variety of designs were computed on different base curves. A +13.00 D. lens was selected to illustrate the findings. Figure 3 shows how a different ocular curve on the same type of correction, affects the deviation from this correction, due to a change in lens power, and the deviation from correction, due to a change in stop position, or eye to lens distance. On this plot, the solid lines represent a 13.00 D. lens, with a flat back; the dash lines represent a 13.00 D. lens, with a 3.00 D. ocular curve, and round dot lines indicate the type of corrections obtained with a 4.00 D. back curve. It can be seen that sensitivity to change in eye position is minimum between ocular curves of 3.00 and 4.00 D., and that for flatter curves, the shorter eye position has a more positive residual error than the longer eye position, and for steeper curves, the

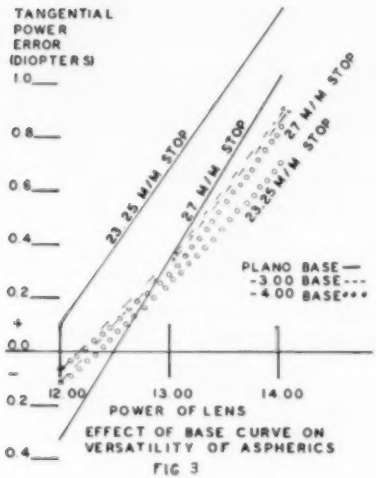


FIG 3

reverse holds true. There are, therefore, two excellent reasons for using a base curve in the neighborhood of —3.00 or —4.00 D. One is lack of sensitivity to stop position, the other is lack of sensitivity to change in prescription or, as we recall, a difference in correction between the two points of the toric.

There is another point to be considered when we consider sensitivity to stop position and that is, that there are two types of acuity with which all patients are concerned—cataract patients and normal patients. The acuity for the dynamic field of view, with the eyes sweeping the lens, and the peripheral acuity for a static field of view; to be sure, peripheral vision is not as acute as central vision but it is important to correct it if we can. To correct both the dynamic and static fields of view means that the lens should be corrected both for the center of revolution of the eye and for the pupil. This means that a lens which is least sensitive to differences in stop positions, will tend to be corrected for both of these fields of view. We now know that we want to keep a minimum error in the tangential meridian and that we want approximately a —3.50 D. base curve.

Figure 4 indicates a skeleton chart, from which a lens series can be drawn up. There are three prescriptions, with two stop positions. It can be seen that for one blank, if the power is increased, the tangential error increases in the plus direction, and if the power of the lens is decreased, the tangential power error increases in the minus direction. The sagittal power is much less sensitive, and can be ignored, except

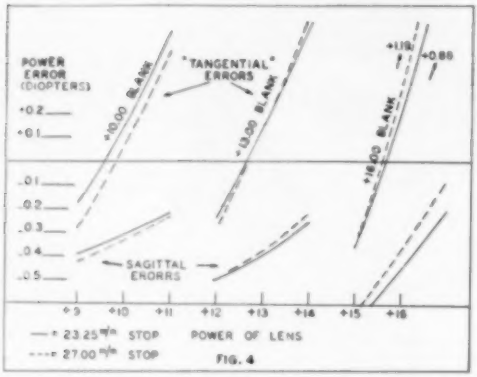


FIG. 4

at the extreme limit of overcorrection. These sloping lines indicate the range of correction available in toric prescriptions. For example, if a +14.00 D. lens is required, with a —2.00 D. cylinder correction, and a 13 blank is used, then a diagonal line reaching through an optimum at 13, going plus at 14, and minus at 12, indicates the correction obtained at the two points of the toric. This diagonal line also indicates what happens if a sphere is put on a blank other than the one designed for it.

If we sketch into Figure 4, diagonal lines for every 0.50 D., it is seen that a lens series can be laid out, indicating at what points it is desirable to change blanks.

We set our tolerances on residual errors and select a blank which will provide undercorrection and overcorrection within this tolerance

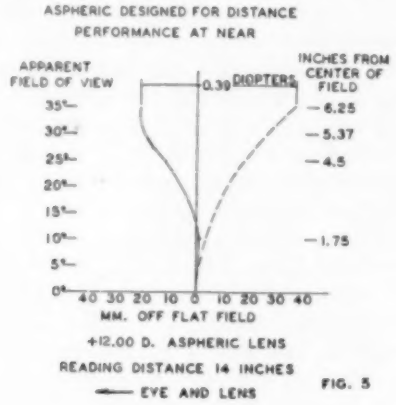


FIG. 5

for both points of the toric. For strong cylinder prescriptions, tolerances must be increased. It will be noted that a slight undercorrection has been selected as optimum. This is to reduce overcorrection for the cylinder meridian of toric prescriptions which generally lie in the horizontal meridian. The 180° line on the most common prescriptions has been favored.

Although the lenses are designed for distance, because most of them will have bifocal segments, they perform well at near. As Figure 5 shows, we obtain a split field with a somewhat flatter correction in the tangential meridian. The total astigmatism for 35° is only 0.4 D.

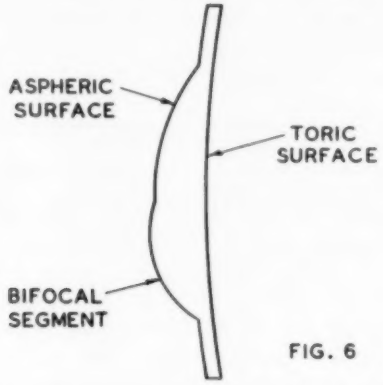


FIG. 6

Figure 6 illustrates a cross section of the finished lens. Weight and distortion data are also of interest and are given below.

Weights	*46 mm. Round Lens*	*+14.00 D.*
Regular glass lens	25.7 grams	
40 mm. Lenticular glass	18.7 grams	
34 mm. Lenticular glass	14.6 grams	
Plastic 40 mm. Lenticular	10.0 grams	
Distortion 27 mm. stop	8.5% aspheric	
+13.00 D. Lens	11.1% sphere	

The above discussion airs some of the compromises and decisions necessary to crystalize the design of an aspheric cataract lens series. Field tests and photographic analysis tend to bear out the validity of the points of view which were assumed.

Experience with these and other aspheric designs and research on the seeing problems of aphakics will undoubtedly point to necessary changes in points of view.

It is hoped that new materials and techniques will become avail-

able to capitalize on opportunities for further improvement, those now known and any that may develop.

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ANNOUNCEMENT

THE CANADIAN ASSOCIATION OF OPTOMETRISTS

The sixth biennial convention of the Canadian Association of Optometrists will be held at the Hotel Vancouver, Vancouver, British Columbia, Canada, July 5, 6, 7 and 8, 1959. The British Columbia Optometric Association will act as hosts and all Canadian optometrists are invited to attend.

This is the first meeting of the Canadian Association of Optometrists in western Canada and Dr. H. C. Arnold, President of the Association, expects a record attendance of optometrists from all Canadian Provinces.

Two speakers from southern California will head the educational program. Dr. P. L. Spencer, professor of education at the Los Angeles State College and director of the Claremont College Reading Conference, will speak on the *Development of Visual Performance from Educators' Point of View*. In addition Dr. E. D. Fletcher, who heads the Department of Review for the Licensing of Motor Car Drivers in the State of California, will present a *Review of Research of Motorist Vision as it Relates to Licensing of Drivers and Highway Safety*.

TRANSMISSION OF THE VISIBLE SPECTRUM THROUGH THE OCULAR MEDIA OF THE BOVINE EYE*

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INTRODUCTION

There is surprisingly little data which can be used to arrive at a sound, scientific conclusion as to just what the ocular transmission of the visible spectrum really is. A search of the small amount of literature concerning the transmission of the visible spectrum through the ocular media reveals conflicting data: the percent transmission is usually described as either "the same as that of an equal thickness of water" or "a little more than 50 per cent of the light incident on the cornea." The present study is a report on measurements of the relative transmission for bovine eyes.

Early ocular transmission studies concentrated on the thermal effects of infra-red and the abiotic effects of ultraviolet radiations on the tissue of the eye. An excellent review, summary and bibliography of the effects of the infra-red and ultraviolet portions of the electromagnetic spectrum and their pathological effects on the eye is given by Verhoff, Bell and Walker[1] (1916).

An early study on infra-red transmission was made by Aschkinass[2] (1895) in which he used a thermopile to determine the absorption spectra of the cornea, lens, aqueous and vitreous of ox eyes. His work did not extend below 670 mμ but represents one of the first attempts at a qualitative study and gave far reaching conclusions. Aschkinass consistently obtained values of lens transmission above 100%. This he attributed to the crystalline lens being pressed between two glass plates thereby eliminating the "concentrating effect of the lens." He corrected for this with a calculation which contained "a certain arbitrariness" in method. He repeated his work on the human eye stating the human and ox results are in agreement and that the absorption of the eye is the same as that of an equal thickness of water.

Hartridge and Hill[3] (1917) used wavelengths from 750 mμ to 2300 mμ and compared the absorption values experimentally obtained

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†Military optometrist. Captain, United States Air Force. Fellow, American Academy of Optometry.

from the cornea, aqueous, lens and vitreous to those of an equal thickness of water. They then derived an absorption ratio for each of the eye components to water, and calculated the absorption by multiplying this ratio by the thickness of the structure and by the percentage of water contained by the structure. They report that "no considerable difference exists between the absorption bands of the eye media and those of water," which agrees with the previous work of Aschkinass.

Martin[4] (1912) reported a study on the visible spectrum incidental to a study of the effects of ultraviolet on rabbit eyes. His source was a carbon arc crater and he took separate spectrophotographs through the cornea, lens and vitreous. He stated that all media were found to be "uniformly permeable" to the wavelengths between 390 mμ and 660 mμ.

Ludvigh and McCarthy[5] (1938) report that Roggenbau and Wetthauer studied the effects of infra-red on cattle eyes and they print a curve extending through the visible spectrum. This curve shows a little more than 50% transmission in the visible region and is the first visible spectrum transmission curve encountered in the literature (see Fig. 2).

The only study of visible spectrum transmission using all human eyes was made by Ludvigh and McCarthy.[5] They reported on four human eyes, ages ranging from 59 to 66 years, which were enucleated for sarcoma of the choroid but which had apparently normal ocular media. Their results show an average transmission of 53.1% throughout the visible spectrum from 400 mμ to 800 mμ. All measurements were completed within one hour after enucleation.

The latest study by Weisinger, *et al.*[6] (1956) was made during a study of retinal damage in rabbits by thermal radiations. Their basic instrument was a Beckman Spectrophotometer in which a Kodak Ektron lead sulfide cell was substituted for the phototubes. Transmission data for nine rabbit eyes revealed a mean per cent transmission between 390 mμ and 700 mμ of 85.5%.

APPARATUS AND PROCEDURE

The basic instrument used in this study was a Beckman Model B Spectrophotometer[7] which incorporates a direct current amplifier with a sensitivity of 5×10^{-13} ampere. A blue sensitive phototube with a maximum sensitivity range of 320 mμ to 675 mμ was used to cover the visible spectrum. A constant supply voltage transformer was used in taking all data. The narrowest monochromator slit possible, but no less than 0.10 mm. was used. The wavelength scale was calibrated to 0.50 millimicrons accuracy and a 0.50% accuracy in measuring the differences between the transmittances of two substances is claimed by the manufacturer.

Two eyeholders were constructed to fit into the sample compartment and were attached to the sample carriage. In one the posterior pole of the eye was directed toward the incident light and in the second the cornea was directed toward the incident light. The eyes were mounted in a horizontal position, i.e., the antero-posterior axis horizontal. Stainless steel was used in the construction of these eyeholders and they were painted with flat black paint to reduce stray light. Each eyeholder could be moved vertically, horizontally or longitudinally to obtain proper specimen alignment between the phototube and the source. On the back of the eyeholder was a glass plate, 1 mm. thick with an index of 1.5179 for sodium light, against which the back of the trephined eye rested. This gave the vitreous a flat optical surface. The sample carriage allows one to align alternately the unknown sample and a comparison standard before the incident beam. The relative transmission in percentage was read directly from the instrument.

The phototube backplate was easily removed to align the eye sample so the beam light passes through the center of the pupil and scleral opening. An opal plastic plate, with the phototube area and the area of the open beam etched on it, could be inserted into the instrument as a viewing screen in place of the phototube. With the screen in place, the image from the eye was aligned in the same place as the open beam area on the phototube for each eye tested. A 2 mm. aperture was located where the light beam enters the sample compartment. A cosine light diffuser was inserted in front of the phototube to eliminate its directional sensitivity. This diffuser was fixed and all readings were taken through it.

The bovine eyes used in all phases of this experiment were obtained from a slaughter house* located ten to fifteen minutes from the campus. The eyes were obtained within ten minutes after death. Six eyes were obtained on each visit to the packing house. Each eye was washed immediately with a 0.9% normal saline solution, carefully placed in a moist glass container, and covered with a saline moistened cloth for the trip back to the University laboratory. This procedure consumed approximately twenty-five minutes.

In the laboratory the eyes were inspected for pathology and possible corneal abrasions with four abrasion and pathology free eyes being selected for specimens each time. All muscle and fatty tissues were removed from the globe and a 1½ cm. square surgical opening was made through the posterior sclera in the approximate position of the

*Bloomington Packing Company, Bloomington, Indiana, graciously supplied the bovine eyes.

macula. The eye was then placed in the eyeholder with the edges of the scleral opening and extruding vitreous pressing against the glass plate.

Mechanical and visual alignment of the eye was made with the monochromator set at a wavelength of 500 mμ. Transmission readings were taken at 10 mμ steps starting at 370 mμ and proceeding to 700 mμ. The dark current was checked for zero position before each reading was taken. Upon completion of the series of measurments a recheck was made at 550 mμ, 500 mμ and 450 mμ. These rechecks were always within 1½ % of the original measurements and most of the time less than 0.50% variation was found. Measurements on the four eyes were completed in less than two and one-half hours.

The temperature of the air-conditioned laboratory was maintained at 72° F. with humidity at approximately 35%. At 50 mμ intervals the cornea was bathed with saline solution to prevent possible dehydra-

TABLE 1

Wavelength in mμ	Transmission in Percent with Light Incident on Cornea ——Transmission Raw Data—— T_1	T_2	T_3	Mean T_m	Corrected T_{cc}
370	9	7	11	9.0	9.8
380	22	18	22	20.6	22.5
390	37	34	35	35.3	38.1
400	49	46	48	47.6	50.8
410	55	53	51	53.0	56.0
420	58	56	59	57.6	60.9
430	64	60	64	62.6	65.6
440	66	64	67	65.6	68.6
450	70	67	69	68.6	71.8
460	71	69	72	70.6	73.8
470	73	71	74	72.6	75.9
480	75	73	76	74.6	77.2
490	76	74	77	75.6	77.5
500	77	76	79	77.3	79.2
510	79	77	80	78.6	80.5
520	81	78.5	81	80.0	81.9
530	81	80	81.5	80.6	82.5
540	82	81	82	81.6	83.6
550	83	81	83	82.3	84.3
560	84	82	83	83.0	85.0
570	84.5	82	83.5	83.3	85.3
580	84.5	83	84	83.3	85.3
590	85	83	84.5	84.0	86.1
600	85	83	85	84.3	87.7
610	86	83	85	84.6	88.5
620	86	84	85	85.0	88.9
630	86	84	85	85.0	89.4
640	86	84	85.5	85.0	89.8
650	86	84	85	85.0	89.8
660	86	84.5	85	85.0	89.9
670	86	85	86	85.6	90.5
680	87	86	86	86.3	91.2
690	86	84	86	85.3	90.2
700	85	84	84	84.3	89.1

tion. An assistant aided in recording and keeping the unused eyes moist with the saline solution.

RESULTS

Table 1 shows the transmission of three eyes with light incident upon the cornea. Table 2 shows the transmission of three other eyes with the light incident on the vitreous. In both Tables 1 and 2 the raw data (T_1, T_2, etc.), mean raw data (T_m) and the corrected mean data (T_{ce}) are listed in their respective columns opposite the appropriate wavelength in millimicrons. All graphs are plotted from the mean corrected data (T_{ce}) with the wavelength in millimicrons as the abscissas and the relative transmission in per cent as the ordinates. Figure 1 gives the curves plotted from the data in Table 1 and Table 2. Figure 2 illustrates the curves plotted to compare the results of this study with the results obtained by three other authors.

TABLE 2

Transmission in Percent with Light Incident on the Posterior of the Eye

Wavelength in mμ	——Transmission Raw Data—— T_1	T_2	T_3	Mean T_m	Corrected T_{ce}
370	12	14	16	14.0	15.3
380	24	23	32	26.3	28.7
390	41	44	46	43.6	47.1
400	47	52	54	51.0	54.5
410	55	56	56	55.6	58.8
420	59	60	60	59.6	63.0
430	63	63	65	63.6	67.2
440	65	66	67	66.0	69.0
450	67	69	70	68.6	71.8
460	72	72	73	72.3	75.6
470	74	74	75	74.3	77.7
480	76	75	76	75.6	78.3
490	78	76	78	77.3	79.2
500	79	78	79	78.6	80.5
510	80	79	81	80.0	82.0
520	81	80	82	81.0	83.0
530	82	80	82	81.6	83.6
540	82	81	83	82.0	84.0
550	83	82	83	82.6	84.6
560	84	82	83	83.0	85.0
570	84	82	84	83.3	85.3
580	84	83	84	83.6	85.6
590	84	84	85	84.3	86.4
600	84	84	85	84.3	87.7
610	84.5	84	85	84.5	88.4
620	85	85	85	85.0	88.9
630	85	85	85	85.0	89.4
640	85	85	85	85.0	89.9
650	85	85	86	85.3	90.2
660	86	86	86	86.0	90.9
670	86	86	86	86.0	90.9
680	85	86	87	85.0	89.8
690	85	86	86	85.6	90.5
700	85	86	87	85.0	89.8

The curves for losses due to reflection (I_r) from air to glass and from glass to vitreous for all wavelengths of the spectrum were calculated and plotted by use of the formula.[8]

$$\frac{I_r}{I_o} = \frac{(n_2 - n_1)^2}{(n_2 + n_1)^2}$$

For ordinary glass the index n is virtually the same for the whole visible spectrum.[9] The loss of light by reflection at the air to glass surface for any spectral wavelength was found equal to 4.2% ± 0.1%. The loss of light at the vitreous to glass surface for any spectral wavelength was found equal to 0.4% ± 0.1%. Therefore, the total loss due to reflection of the light in passing through the glass plate is 4.6% ± 0.1%. This loss would be the same whether the light were incident from the posterior of the eye or from the cornea. The per cent loss of 4.6% was used as a correction factor in arriving at the total transmission percentage.

To obtain the total transmission a proportional relationship was used. The correction factor of 4.6% was added to the transmission data of the glass plate: $T_g + 4.6\% = T_{gc}$ where T_{gc} is the corrected transmission of the glass plate. T_{gc} was then used as the 100% source. The total corrected transmission (T_{ce}) of each of the eyes was then calculated by use of the formula. $T_{ce} = \frac{T_m \times 100}{T_{gc}}$ where T_m is the experimental mean transmission. The calculation figures for each wavelength are shown in Table 1 and Table 2 under column T_{ce}.

No corrective factors were necessary for the diffuser because it was placed before the phototube while both the standard (air) and the eye measurements were taken.

DISCUSSION

In perfecting a technique, the instrument would give seemingly satisfactory readings for all wavelengths for an eye and then would suddenly show a marked change of as much as 15% on the next eye. A re-evaluation of the technique and the apparatus revealed that inconsistent alignment of the transmitted beam on the phototube resulted in a change in readings because of the directional sensitivity of the phototube. The alignment procedure outlined in the previous section and the use of an opal diffuser mounted in front of the phototube eliminated this problem.

A total of 28 bovine eyes were used during numerous experimental sessions: however, 17 were required to perfect the technique and are not reported. Good experimental data for five eyes, taken without the diffuser, after the alignment technique was perfected, are not included in

this report. The decimals in the measurements were dropped if under 0.5% and, if above, they are recorded as 0.5%. A check for leakage of room light into the sample and phototube compartments indicated they were light proof.

The scleral opening of the eyes undoubtedly reduced the intraocular tension but with no apparent harm to the results. The scleral opening and the vitreous were in contact with the glass plate during the entire measurement procedure and provided an excellent seal for the intraocular fluids. The eyeholder applied enough pressure to the eye to maintain a normal corneal curvature: hence, the lens was probably kept in its normal position. Placido's disc revealed no wrinkles on the cornea. The cornea was moistened with an eye dropper at 50 mμ steps to prevent dehydration.

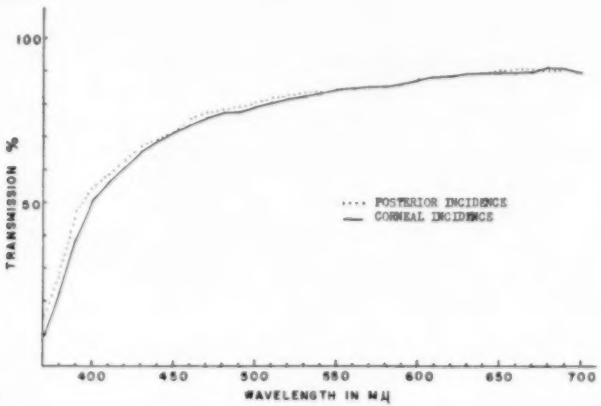

Fig. 1.

Figure 1 is a comparison of the curves in per cent transmission of the light with corneal incidence and posterior (vitreous) incidence. These curves show an 80.5% mean transmission for the bovine eye over the spectral range of 400 mμ to 700 mμ with slowly decreasing transmission from 700 to about 500 mμ and a more rapidly decreasing transmission below 500 mμ. Transmission for the bovine eye is about 9.8% at 370 mμ and about 91.2% at 680 mμ. A slight difference between these curves is noted between 370 mμ and 550 mμ. The obliquity of the incident light upon the curved corneal surface vs. the normal posterior incidence would be expected to give a slight difference. More important, the two curves were obtained on successive days with different eyes, therefore, the differences are undoubtedly insignificant.

Boynton, Enoch and Bush[10] reported a method of correcting for

post-mortem transmission losses in excised eyes. Correction for post-mortem changes in this study has not been made since their data indicates an error of less than 5.0% could be expected at two hours. Post-mortem changes decrease ocular transmission, hence a correction for this would result in a small increase in the relative transmission in this study. Age is also reported to be an important factor in the transmission of radiant energy through the human ocular media.[11] This factor could be expected to be found in other species as well. The slaughter house indicated the eyes used in this study were from young healthy cattle.

In comparing the curve from the study by Ludvigh and McCarthy to that obtained by Wiesinger, *et al*, and that obtained in this study (Fig. 2) one must look for an explanation for the differences. Species could

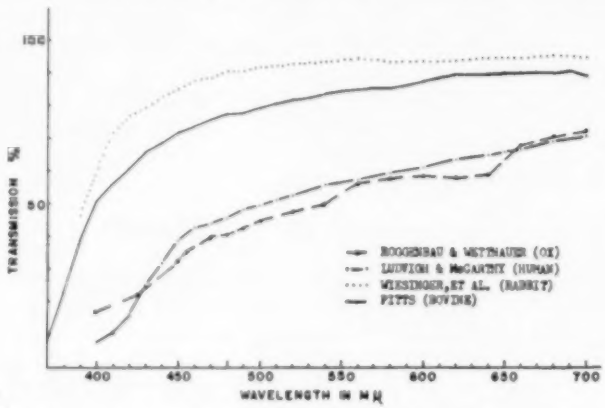

Fig. 2.

be one difference but it is felt a 22% transmission difference could not be explained by species differences alone. Comments by LeGrand[12] relative to the data of Ludvigh and McCarthy are so ably expressed that I quote, "This low transmission of the ocular media seems surprising, and since no biological reason can be advanced to justify it, it seems that nature must find it impossible to produce materials of higher transparency." LeGrand continues, "The true absorption of such an amount in a young subject seems questionable." From the data of Wiesinger, *et al*, and this study it appears that nature does produce materials capable of high transparency for the eye. Why, then, would nature be so selective to produce a lower transparency for the human eye?

The experimental apparatus, procedure and controls of Ludvigh and McCarthy appear to be well designed and executed. The correction

in changing the lens age of 59-66 years to 21.5 years to arrive at a final transmission per cent appears in itself to be questionable, but even more disconcerting is the fact that their raw data must have shown even less transmission. Age factors between the 21.5 year human eyes and comparatively young animal eyes may present more differences than is expected. It should be emphasized that this speculation is an attempt to reconcile data differences and the true cause of such low transmission is not understood.

In reference to the transmission of the human eye, Duke-Elder[11] states, "the media of the eye vary in transmissibility, not only between species, but between individuals of the same species." Shoji[13] reports the absorption of the cornea and lens varies somewhat in different animals but that the aqueous and vitreous show less species difference. Graham[14] reports that, although her data are not definite enough to be conclusive, the absorption does not differ radically in animal and human eyes. Boynton, Enoch and Bush[10] concluded that they had not demonstrated any difference in their data for the steer, cat and human eyes.

The comparison of the curve obtained by Wiesinger, *et al*, and the curves of this study (Fig. 2) reveals a substantial agreement in relative transmission; however, there is some difference between the curves. Since the rabbit eye is approximately one-half to one-third the size of a bovine eye, the transmission would be expected to be a little greater through the rabbit eye. From the study of the literature it would seem that an inference to human eyes can be made with some assurance of validity; however, definite transmission factors for the human eye cannot be established without proper experimental data. With the same manner of reasoning as used in comparison of the rabbit data with the bovine data, the human eye could be expected to lie somewhere between the bovine and rabbit eyes, or, at approximately 80 to 85%.

From this study it may be concluded that the transmission of the eye at the red end of the visible spectrum is quite like that of an equal thickness of water and the transmission progressively decreases through the visible spectrum until, at 370 mμ, it is approximately 10%.

SUMMARY AND CONCLUSIONS

A method is presented for measuring the relative transmission of the visible spectrum through enucleated eyes. With this method the mean relative transmission obtained through bovine eyes from 400 mμ to 700 mμ was found to be 80.5%; it was 90% at 700 mμ and decreased to 9.8% at 370 mμ. Post-mortem changes may have produced a maximum possible error of 5.0%.

The human eye transmission, including losses by reflection, over

the same wavelength range, is estimated to be approximately 80% to 85%.

A discussion and an attempted resolution of the conflicting data for various authors is made.

ACKNOWLEDGMENTS

The author is grateful to Dr. M. J. Allen for his encouragement, comments and helpful suggestions and to Dr. Ingeborg Schmidt for translation of the references in German.

The contents of this article reflect the personal views of the author and are not to be construed as a statement of official Air Force policy.

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APPOINTMENT: Dr. Ralph E. Wick, Rapid City, South Dakota, vice-president of the American Academy of Optometry, has been appointed to the National Advisory Committee for the White House Conference on Aging by Mr. Arthur S. Flemming, Secretary of the U. S. Department of Health, Education and Welfare. The first meeting of the Committee was June 9 and 10.

THE EFFECT OF AGE ON THE ACA RATIO*

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In a paper presented at the 1940 annual meeting of the American Optometric Association[1] the following hypothesis was formulated concerning the relationship between the neural mechanisms subserving accommodation and accommodative convergence.

> The different pathways to the ciliary muscle can be traced back with considerable certainty to the Edinger-Westphal nucleus. It must be assumed that this nucleus is connected with the cortex by a set of cortico bulbar fibers and if it could also be assumed that these fibers give off collaterals to the centers in the brain stem regulating convergence this would account for the convergence associated with accommodation.

It was also further stated:

> As age increases the resilience of the crystalline lens decreases and if the innervations to accommodation and accommodative convergence remain relatively constant for the various ages, the increased effort at accommodation at the near point should result in a trend toward esophoria.

However, attention was called to the finding of Eames[2] that exophoria at near increases with age. This was taken as an indication that the innervations to accommodation and accommodative convergence do not maintain a fixed ratio at all ages.

Somewhat later the writer[3] suggested that this kind of data might also be used as evidence for the Hess theory that no more innervation is required to produce a given change in accommodation at one age level than at another. The corollary of this is that as age increases and the amplitude drops there is also an increase in excess contraction of the ciliary muscle over and above that required to bring accommodation to its maximal level.

Since then the studies of Fincham[4] and Van Hoven[5, 6] have conclusively demonstrated at least in certain subjects that no excess contraction exists, and hence the writer decided to take a closer look at the data bearing on the relation of the ACA ratio to age.

The author has participated in several experiments over the past twenty years in which controlled measurements were made of the relation between his accommodation and convergence. Four different graphs of this relation at different ages can be found in the literature.[5, 7, 8 and 9] A study of these graphs shows the gradual collapse of the zone of clear single vision and most important of all it gives a clear picture of the change in the ACA ratio with age.

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†Optometrist. Ph.D., Director of School. Fellow, American Academy of Optometry.

The 1938 paper did not include the phoria data which were made in connection with the study. The ACA ratio computed from these unpublished data is 3.33° per diopter.

The ACA ratios at the different ages have been plotted in Figure 1.

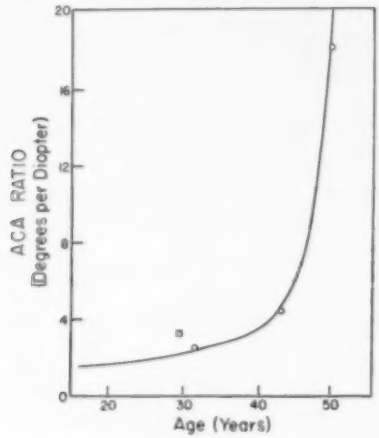

Fig. 1. The variation of the ACA ratio with age.

The change in the ACA ratio with age can be accounted for by assuming that a maximal contraction of the ciliary muscle is required to produce a maximal accommodation at any age and that each fraction of the amplitude of accommodation corresponds to an equal fraction of the total response of the ciliary muscle. This means that the ACA ratio must be inversely proportional to the amplitude of accommodation. Duane's data[10] for amplitudes at different ages can be used to demonstrate this idea, but it is necessary to correct these data to make allowance for the depth of focus of the eye. Hamasaki, Ong and Marg[11] have shown that when the amplitude of accommodation is measured with the punctometer, it is found to be zero at the age of about 54. It is necessary therefore to substract one diopter from Duane's measurements of amplitude to make an allowance for depth of focus. The curve used to fit the data in Figure 1 conforms to the following equation

$$\text{ACA ratio} = \frac{1.8}{\text{amp} - 1.00},$$

where amp represents Duane's value for the amplitude at a given age and the constant 1.8 applies to the subject whose data are being plotted. Unfortunately the author's amplitude was not accurately measured at

the time of the first two studies, but it was 5.5 D. at the age of 43 and 0.75 D. at the age of 50. The deviation of the ACA ratio at the age of 29 from the theoretical curve is probably within the range of variation of the ACA ratio from hour to hour. Obviously this experiment will have to be repeated with other subjects.

It may be concluded that the changes in the author's ACA ratio with age conform to the simple hypotheis proposed in 1940. There are three propositions that need to be considered.

1. The upper limit of accommodation is set by the limit of the ciliary muscle to contract and not by the ability of the lens to respond to such changes.

2. The lens becomes less pliable with age and a stronger contraction of the ciliary muscle is required to produce a given change in accommodation.

3. There is a fixed linkage between the neural mechanisms subserving accommodation and convergence such that at submaximal levels of accommodation there is a fixed change in the innervation to accommodative convergence associated with each change in the innervation to accommodation.

The first proposition can be proved by other types of experiments.[6] If we also assume that the third proposition is true, then we can deduce the second from the data in Figure 1.

Most of the previous studies have failed to show the rapid increase in the ACA ratio between the ages of 40 and 50 which must occur in every individual.

Davis and Jobe[12] using orthorater data were the most successful. They did show a rise in the ACA ratio between the ages of 35 and 45, but found a subsequent drop. None of their subjects wore a correction for presbyopia and the older subjects being unable to focus clearly on the "near" target probably made less effort to focus than younger subjects.

Morgan and Peters[13] compared presbyopes (45 years and older) with prepresbyopes and failed to find a difference in the average ACA ratios. They used a method of measuring the phorias which did not permit a determination of the discrepancy between the stimulus to accommodation and the acccommodative response. According to the writer's data and those of Davis and Jobe the choice of the age of 45 for dividing the two groups was not at all fortunate and dividing all ages into two groups proved also to be a bad choice. Morgan and Peters concluded from their results that what is needed is a controlled haploscopic experiment on subjects between the ages of 40 and 50. This is also born out by the writer's data.

Alpern and Hirsch[14] found a gradual decrease in the ACA ratio with age. Their subjects were grouped into five-year intervals. It is not known at what distance the near tests were made nor is it known whether any allowance was made for near point adds in computing the ACA ratio in the case of older subjects. Certainly no allowance was made for the discrepancy between the stimulus to accommodation and the actual response.

Eames[2] and Tait[15] have made similar studies. Each divided his subjects into the following groups: 0-19, 20-30, 40-59, 60 and over. Eames expressed his data in terms of phoria at distance and at near. The near distance is not specified nor is it specified whether the subjects wore their spectacles. The near phoria shifted toward exophoria with age while the distance phoria showed little or no shift. The age groupings prevent us from learning anything about the variations in the critical range from 35 to 50.

Tait used clinical tests to measure phorias at 20 feet and 13 inches, and computed the accommodative convergence (prism diopters) in accordance with the following formula:

$$\text{Acc Con.} = \text{Phoria}_{\text{Dist}} - \text{Phoria}_{\text{Near}} + 18\Delta.$$

An exophoria is positive and an esophoria is negative.

He determined median values for his four age groups and found this to decrease with age. The subjects wore their distance corrections for the distance phorias and their near corrections for the near phorias so that 3 diopters of accommodation was not required in the near tests for the older subjects. It is not possible therefore to make an assessment of the ACA ratio for the age groups from 40-59 or the group of subjects over 60.

Since the amplitude drops to about one diopter at the age of 50 and since the depth of focus is at least this great it has no meaning whatever to use clinical tests to evaluate the effect of age on the ACA ratio beyond the age of 50.

It should be possible to make reasonable assessments of the ACA ratio from clinical data obtained for ages below 40 provided phorias are measured at various levels of accommodation extending from zero to the highest levels. It would be interesting to compare these data with measurements made on a haploscope which can determine the amount of accommodation actually in play. It would be especially helpful to have a study of this type for the age range from 20 to 40. Below 20 growth, maturation and the development of various visual skills might present special problems.

Fincham[4] has shown that the slope of the convergence accommo-

dation curve decreases with age, but Balsam and Fry[9] have shown that the relation of the curve to the zone of clear single vision is such that its slope would have to decrease with age even if the ACA ratio remained unchanged. Hence the effect of age on the convergence accommodation curve does not in itself prove as Fincham claimed that the amount of ciliary force required to produce a given change in accommodation increases with age.

The convergence accommodation curve involves a combination of fusional and accommodative convergence, whereas the phoria line gives the pure relation between accommodation and accommodative convergence.

The finding that the slope of the phoria line decreases with age especially in the age range from 35 to 50, does prove that the ciliary force required for a given amount of accommodation increases with age. Thus the author has reached exactly the same conclusion as Fincham, but by a different approach.

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ANALOGS AND MODELS OF THE HUMAN VISUAL SYSTEM*

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INTRODUCTION

Man's attempts to understand himself or to make models of his functions are by no means new. Concepts of automata such as the legendary Golem, the half man-half robot of the 16th century, or the 18th century speaking machine of von Kempelen[1] indicate that analogs of human behavior are very old. This artificial-voice mechanism actually existed; constructed of bellows, reeds and adjustable resonant enclosures, it was able to produce strikingly realistic speech. This was in 1791.

It has been only within a relatively few decades that our rapid theoretical and technological advances have provided the basis on which to start building adequate models of the intricate mechanism that is man. Chemistry, physics and optics had to wait for concepts supplied by cybernetics, neuroanatomy and psychology. Our present accomplishments, though many and large, have only sketched in a few faint outlines. A complete understanding of man will undoubtedly depend on many principles and an enormous number of facts yet to be disclosed. This paper briefly surveys some of the representative problems and recent accomplishments in understanding and modeling vision.

The visual system of the human organism accounts for over 90% of all the information input to the brain. The 130 million or so receptors in each eye are channeled into about a million optic nerve fibers while the auditory nerve has only about 30 thousand. The other sense modalities, such as touch, pain, equilibrium, taste, smell and temperature account for only a few per cent of all nervous pathways feeding the brain.

The problems of understanding the form and function of the visual system are myriad. They range from the front surface of the cornea to the ultimate projection areas in the occipital lobes of the cerebral cortex.

We must understand essentially three transformations. The first one involves the projections of rays of approximately one octave of

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electromagnetic radiation from the environment onto the retinal surface. This is principally the domain of optics, but the time-varying properties of the eye must also be included in an adequate description. The refraction parameters and their aberrations are difficult enough to describe; in addition the several motions of the eye and its parts profoundly modify the projected retinal image. Thus we must understand the dynamic lenticular and saccadic functions, for example, as well as the static physiological optics.

The second transformation to be understood in a complete model of vision is the conversion of the retinal image into primitive neurological signals. This process is the concern of those who study photoreception and deals mostly with photochemistry. It is at this point in the visual process that the temporal sequences of illumination are converted into chemical changes, electrical currents, and even some physical motion (since pigment migrates under strong illumination). Here also an understanding of the eye movements is essential, for it is now well known that normal vision disappears if the retinal image is artificially held stationary.[2]

The third transformation is, at our present level of knowledge, the least understood. It has to do with changes of the photoreceptor electrical potentials into the ultimate signals which are found in the optic nerve. The complex, cross-connected ganglionic structures which connect the photoreceptors to the optic nerve fibers apparently have properties of summation, facilitation, inhibition and even feedback from the brain. All these modify the ultimate representation of the retinal image in the cortex. It is within this neural structure of the retina that the 130 million photoreceptors appear to branch down to only about one million optic nerve fibers, a reduction of over 100 to 1.

At this point, let us arbitrarily locate the termination of the human visual system at the end of the optic nerve, that is, just at the brain. It is then analogous to an input system serving a data processing computer, and this ensuing computer—the brain—can be considered as connected to several such inputs, and similarly to a variety of outputs.

The input system transformations just discussed, visual field to retinal image to photochemical potentials to optic nerve signals, are not well understood. This multiple encoding of the objective visual world has resulted in a welter of frequency-modulated pulses traveling along a million channels. What then happens to these signals, how the cerebral computer processes this stream of data, is even more obscure.

A very convincing example of the strange and wonderful mechanisms involved here is found in Sperry's[3] experiments with amphibia. He

found that if the optic nerve of a frog, for example, is severed and allowed to grow back together, the animal afterwards behaves as if it sees quite normally. Now in another experiment if the eye is surgically rotated 180° and the optic nerve is cut and allowed to regrow, the frog acts as if his visual world had been inverted. Careful examination of the healed optic nerve shows a tangled mass of fibers which very clearly have not grown back in correspondence with the original connections. All the nerve lines are now randomly cross-connected.

The incredible situation is that in both cases the brain knows the orientation of the eye and can interpret information sent back from that organ even though all the connecting lines have been switched around. It is as though a blind lunatic had rewired a telephone central office and yet all calls still got dialed through correctly. Somehow the visual areas of the brain must have been able to reorganize themselves to accommodate for these profound changes in input information.

Models of visual function can be derived from two completely different approaches. Along one avenue is the attempt to describe and understand the biological system in the small, and in its entirety. Here one seeks knowledge of nature's building blocks—the optical structures, the photoreceptors and the neural elements—and explores their interrelated functions. However, there is another avenue, one which is not necessarily concerned with nature's building blocks but seeks only functional equivalence in the large. With this (synthetic) approach, one tries to achieve similar over-all system behavior by using any elements and techniques which come to hand.

Each of these courses is important although admittedly only the former will eventually describe nature accurately. While the latter approach is primarily concerned with finding efficient ways of achieving functions grossly similar to those in nature, some of the principles which are involved may well shed light on problems in the biological domain. This point will be amplified later. Hopefully the understanding created by both lines of endeavor will lead to economical descriptions of systems which provide useful, efficient information processing.

There have been a considerable number of analyses and models of parts of the human visual apparatus and a few which for limited functions, extend over the entire system. A small number of functional analogs have also been created. These are mathematical models and real machines which may seem anthropomorphic in their behavior but which have no necessary internal relationships to nature.

Let us first consider some of the analytical models, those derived from nature.

ANALYSES AND MODELS

Perhaps one of the most extensive treatments of the visual system from a mathematical standpoint was given by Schade[4] in 1956. Starting with physiological and psychophysical data he was able to draw together in a single comprehensive model the various relationships of luminance, spectral response, storage time constants, rod and cone function, contrast sensitivity, and noise perception.

This model, purely hypothetical and often ad hoc, starts from the lens, proceeds through the photoreceptors and cell structure of the retina and continues through the optic nerve. For example, there are computations for the primary transfer function of the retinal illumination to receptor output, and calculations are made for such parameters as the relative gain characteristics of rods and cones. These computations are in reasonably good agreement with values derived from measurements made on human observers.

This sort of model, by codifying and quantifying some of the intricate relationships found in the human visual system can be very valuable in bringing simplification and understanding. Often, however, such purely mathematical constructs are barren. They might well be extended by a computer simulation or by actual construction. Unless such a relatively complete abstraction is checked out thoroughly in the real world, it may be no more than brilliant but arid intellectual exercise.

Representative of the mathematical treatment of portions of the visual equipment is Stark and Sherman's study[5] of the pupillary reflex arc as a servo-mechanism. In these experiments the rate of change of the diameter of one pupil is measured when light is suddenly applied to the other. Other measurements are made when the intensity of illumination is slowly varied in a controlled manner. Data from these experiments are analyzed and fitted into relationships where the retina-brain-pupil loop is shown to behave very much like some of our man-made feedback servosystems.

These and similar studies[6] produce relational descriptions rather than functional models but they illustrate the important point that many complex biological mechanisms may be adequately described in fairly simple terms. This descriptive clarification is often helpful in achieving more fundamental understanding.

The phenomenon of flicker-fusion has received extensive study: a 130-page bibliography was published by Landis[7] in 1953 and considerable work has been done since. This deceptively simple subjective effect is that if a light source of any arbitrary intensity is repetitively turned on and off, there is always some rate above which it appears to be steadily on.

that is, flicker changes to fusion. This effect depends on many variables besides intensity and rate: among them are color, retinal area, background and ambient illumination, light-to-dark ratio and subject fatigue.

Intensive studies of photoreception at the molecular level have been made by Wolken[8] and others, the object being to investigate the micro-structures of receptors, correlating them with physiological functions. Inferred models of biochemical processes have been experimentally verified and used to probe deeper into the mechanisms of light-energy to chemical-energy conversion.

One of the most interesting aspects of the visual mechanism is found in the interconnected retinal neuron structure. It is here that differential responses to simple stimuli occur. Hartline, Ratliff[9, 10] and their collaborators have described the unique "on" and "off" receptor cell responses where some retinal elements respond only when excitation is increased and others respond only for decreasing illumination. They have also shown how simple mutual inhibition of cells in a retinal array can account for enhanced perception of edges in the visual field. Other studies[11] have detailed the organization of local receptor fields: apparently, the retina is divided into many separately organized clusters of cells, each of which has one of several unique responses to stimulation.

These findings strongly suggest that some of the structures lying between photoreceptors and optic nerve have very useful information processing functions. Perhaps some simple pattern recognition occurs here: possibly some of the subjective flicker-fusion decisions are made at this level. Such considerations have led me to attempt some model-making. This has been more analog simulation than direct physiological modeling. A brief description of the work will serve as a preface to a discussion of the second class of models, the purely synthetic, functional analogs.

This work began with the creation of an electronic analog of a nerve cell, a model neuron. Simulation of neurons in itself is not novel: in the past, this has been done chemically,[12] electrically,[13] and by digital computer programming.[14] The present model,[15] being electronic, is versatile and flexible. It has built into it most of the basic properties of neurons, as well as we know them—spatial and temporal summation, inhibition, variable refractory period, and all-or-none output.

By providing photocells at the inputs to these circuits, and by very simple interconnections between cells, it is easy to obtain sequences of output pulses which have certain functional relationships to the incident light. Some cells produce pulses only when the light is increasing, some fire only for decreasing illumination: others put signals out only during

constant illumination and not otherwise. Here then are artificial "on," "off," and "during" receptors.

Similarly, it is not difficult to arrange such cells in an array to demonstrate, by mutual inhibition of neighboring elements, sharpening of image boundaries. Flicker-fusion phenomena can also be arranged such that the output of a model neuron will change abruptly if an intermittent light of constant intensity increases its flicker rate past a certain value. This critical rate increases with increasing intensity, up to a limit. Such performance is a primitive simulation of critical flicker-fusion.

The behavior of these models is not unexpected since the circuits were built with all the basic parameters needed for such operation. The apparent similarities to biological function are consequently anticipated. It is hoped, however, that by arranging for more complex behavior other, perhaps unexpected, functions will be found. If these new properties are similar to those found in nature, then our modeling has been accurate and extendable. In this event, one may find that the artificial model furthers understanding of the biological original.

FUNCTIONAL ANALOGS

Pattern recognition research has produced many systems having behavior which resembles that of the living visual apparatus. However, outside of occasional rather crude functional similarities, there is little in common. These systems, for example, are the printed-character readers, line-drawing recognition machines, and various tracking and navigation devices. They are functional analogs of the human visual system in so far as they process visual information so that ultimate responses resemble those which a human observer might make.

The character reading machines are typified by such commercial devices as those made by the Intelligent Machines Research Corporation.[16] These readers scan a line of print with photoelectric and mechanical equipment and the resulting electrical signals are processed in a small special-purpose computer. Over 300 characters a second can be read automatically with a very low error rate.

Such equipment works reliably only on a limited style and size of type. Considerable effort is being expended by many organizations to produce readers of a more general nature. Truly powerful systems will be those of the future which will be able to read machine or hand-printed numbers and letters irrespective of size, precise style, or rotation. It is this sort of general pattern recognition which is important because an understanding of concepts in this area may bring greater understanding of human information processing.[17] We have, to date

no really powerful tools or principles with which to produce "universal" recognition systems; however, one or two modest devices have been put together.

There are other classes of machines which are built as substitutes for man's entire visual system. These are the devices for prosthetic aid to the blind. It is impossible, of course, to produce any but the crudest substitutes at this time, but some of them have been quite ingenious. Many operate acoustically, emitting sounds which are detected after being reflected back from obstacles. There are also several interesting visual ranging devices which emit no probing signals and use only the ambient illumination for their input.

One system of this type, devised by H. E. Kallman[18] in 1954, explores image space by an optical-mechanical scanner which produces various audible tones corresponding to the ranges of visible targets in its field. This device makes use of the fact that the shallow real images of objects formed by a wide-aperture lens can be accurately located by a suitable scanning system. The image planes corresponding to objects at various distances can be discriminated with reasonable accuracy; this information, converted into audible tones, informs the user of the presence of obstacles and their distances.

PROBABLE FUTURE DEVELOPMENTS

The visual information processing machines that will probably be developed in the near future will make our present accomplishments seem quite meager by comparison. The line-drawing and character recognition systems will be improved and extended to include automatic detection of complex outlines such as radar-scope presentations and maps. Readers of hand-printed letters and numbers will be evolved into devices for reading handwritten script.

At some not-too-distant time the simple black-and-white line drawing detections will be replaced by operations which can evaluate a visual field having many levels of illumination. We may then be able to try for automatic recognition of complicated three-dimensional objects, for example, faces. These and other devices in conjunction with computers will be capable of processing visual data derived from the real world of moving objects. These systems will make decisions based on this information and then direct the operation of other machines. In a very real sense, they will be able to "see." The crude beginnings of such functions may be found today in some of our missile guidance systems and automatic manufacturing processes.

Our direct understanding of the human visual system is far from complete. At the most basic level, we still do not have a complete pic-

ture of the neuron: although many of its properties have been described in fair detail, the input-output relationships of a single cell are not fully known and have yet to be directly measured. Somewhat further up the structural scale, we need accurate models of such functions as fine-line acuity. It is no trivial mechanism which can detect a line, the thickness of whose image is only one-sixtieth the diameter of a single receptor cell.[19]

At the more complex levels of visual system organization there is the need for analyses and models to elucidate the organization of optic nerve signals. Here the visual world is coded into meaningful nervous impulses by the organism. Of course, beyond all this is the fundamental mystery of how these nervous impulses are processed by the brain.

We have come a very long way from the physiology of earth, air, fire and water, and an equally long way from machines of wooden gears and ropes and pulleys. We still have far to go.

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ANNOUNCEMENT

ANNUAL MEETING OF THE BETTER VISION INSTITUTE

Mr. M. J. Julian was reelected president at the annual meeting of the Better Vision Institute which took place on Friday, May 22, at the Park Lane Hotel, New York City. New directors were elected for two-year terms, and new finance committee members for one-year terms.

The directors chosen were as follows: Manufacturers—Herman Goodman, A. Kono, Hutson Titmus, Nicholas Vitello: supply house representatives—Otto Batzli, William Driscoll, Norman MacLeod, Morton J. Wolper: optometrists—Dr. Benton F. Lyman, Dr. Martin R. Snook, Dr. Lester L. Thomas, Dr. William G. Walton, Jr.: ophthalmic dispensers—Joseph L. Bacotti, Mrs. Elizabeth E. Harris, Herbert W. Hoskins, Bernard J. O'Donnell.

Those elected to serve on the finance committee were: Manufacturers—A. K. Marsters, Hutson Titmus, Nicholas Vitello: supply house representatives—Roy D. Martin, L. W. Myers: optometrist—Dr. L. H. Sugarman: ophthalmic dispenser—C. Arley Farmer.

President M. J. Julian announced that the membership tally now stands at 20 manufacturers, 130 supply houses, including seven new ones, 2,383 associates, and two donors.

A CLINICAL EXPERIMENTAL STUDY OF CORNEAL CONTOURS IN THE FITTING OF CONTACT LENSES*

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It is apparent that the corneal periphery is playing an increasingly important part in the prescribing of corneal contact lenses. It seems that there is general agreement in the near sphericity of the corneal optical or regular zone and in the gradual flattening of the corneal periphery. It also seems that there is general agreement that the corneal periphery is more or less parabolic in form and not spherical. There is also general agreement that the diameter of the corneal optical or regular zone varies considerably. Most authorities are quoted as stating that this zone varies from 4-8 mm.

Most optometrists are familiar with the Bier papers on the corneal contours and contour lens, all of which are now embodied in his text *Contact Lens Routine and Practice*. The Bier concept of the corneal contours which includes a "negative zone," described as a depressed annulus surrounding the optic cap, seems to have provoked the greatest discussion. I was told by a recent English visitor that the majority of English practitioners do not accept this concept. I know that there are quite a few American practitioners who question the existence of this zone. The experience of the writer bears out the Bier concept and tends to prove the existence of this zone.

The experimental work done by the author was performed in such a manner that only clinical instrumentation was employed. Nothing was attempted or utilized which could not be employed by the average contact lens practitioner. This is a report of this clinical study. The purposes of the study were as follows: (1) To examine, clinically, the existence of the corneal "negative" zone. (2) To determine the diameter of the corneal optic cap (regular zone). (3) To determine the amount of corneal peripheral flattening, and (4) To determine a procedure whereby these findings may be used and correlated.

The writer feels that in order to prescribe corneal lenses which will prove as adequate months and years from now as during the first few months they were prescribed, certain pre-requisites must be met. These are (1) To provide a lens construction which will not result

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in a flattening or steepening of the corneal dome, and (2) To provide a lens construction which will not interfere with the normal lacrimal flow and oxygen supply. Since the above criteria are interrelated, if either are grossly interferred with, the patient wearing the lenses will, sooner or later, start to lose wearing time. This has been referred to as "corneal insult" and as "corneal exhaustion."

Chosen for this study were 10 patients, all of whom had near spherical corneae as measured with the B&L keratometer. These corneae varied from 42.50 D. to 46.37 D. All were wearing corneal lenses without any objective or subjective symptoms for more than one year. All were capable of interchanging with spectacles without any change in visual acuity. All were myopic ranging from 2.50 D. to 5.25 D. All of these patients were originally prescribed for following the concepts of the Contour principle. By this is meant that there was central contact or a bearing surface covering about ⅔ of the lens diameter with peripheral clearance.

Since this was a clinical study the equipment used was limited to clinical equipment. The following items were used: (1) A series of ventilated single radius lenses with a 1 mm. flatter ¼ mm. flange ranging in diameter from 3 to 7 mm. in ½ mm. steps and conforming with the patient's corneal readings. (2) A series of multiple radii lenses ranging from 5 to 10.5 mm. (3) Fluorescein. (4) Burton Lamp. (5) Slit-lamp (study purposes only). (6) Suction cups. (7) Keratometer, and (8) Spindle 7 radius tools.

The procedure: The patient was placed in a prone position with gaze fixed on a point in the ceiling. Single radius lenses, the same radius as the corneas, were then placed successively on the cornea starting with the 3 mm. lens until that lens was reached which would, under fluorescein study, create a green pool under the lens. The assumption reached from this was, that the diameter of the lens prior to the one which created the fluorescein pool was substantially the same as the diameter of the corneal optic cap or regular zone.

The next lens chosen was ½ mm. larger than the lens which clinically we determined to be the same as the corneal optic cap. Next a peripheral radius was placed on the lens .1 mm. flatter and .50 mm. wide. Then the peripheral radius was increased in depth and/or flattened until the fluorescein pool in the center was completely eliminated. The next step was to use wider and wider lenses keeping the optical zone diameter constant and placing on the lens, flatter and flatter edge radii, each previous zone remaining the same. An average of nine lenses were used up to 10.5 mm. in diameter in each case. The amount of peripheral

flattening to achieve a tangent fit varied from case to case, but each successive step averaged .1 mm. and about ¼ to ½ mm. in width. The writer cannot be more specific as to the flange width because in most instances the amount was almost impossible to measure.

No conclusion may be arrived at on the amount of peripheral flattening and flange width because ten cases are not a large enough sample. However, these results seem to bear a definite relationship to the final conclusions in the recommended clinical procedure. In all cases the amount of peripheral flattening required was practically uniform up to a point when a more severe peripheral flattening was required to maintain the tangent fit. The diameter of the lenses up to this point varied from 9.7 mm. to 10.2 mm. At this point, an increase in flattening was definitely required to prevent a central fluorescein pool. The amount of increase over and above the previous peripheral flattening averaged .1 to .2 mm. This resulted in my personal opinion that the negative zone, as described by Bier, very definitely exists and can, in fact, be clinically demonstrated and measured.

The study has revealed that if we are to succeed in prescribing corneal lenses, we must, of necessity, consider the corneal variables. We must, as well, consider those factors which are a prerequisite to corneal lens prescribing and correlate them.

In the writer's opinion, a corneal lens should not be prescribed if the lens causes any demonstrable change in corneal physiology. The cornea should not be flattened; it should not be caused to steepen; corneal edema should be prevented; the normal flow of lacrimal fluids must not be interfered with. To achieve these factors, in the majority of patients, it is necessary to prescribe a lens which is substantially the same in its central radius as the corneal apex. There must be no binding areas surrounding the corneal optic cap and the lens periphery must be flatter than the corneal periphery. In other words a lens which tends to ride centrally, with no pressure at superior limbus.

The corneal variables with which we are concerned are therefore, (a) the optical or regular zone, (b) the negative zone, (c) the positive zone, (d) the diameter of the regular zone, and (e) the visible iris diameter.

If one is desirous of actually measuring the optic cap in each patient, the following procedure may be adopted: Have single radius lenses in .05 steps made up from 7.2 mm. to 8.4 mm. Each lens in 3 diameters, the steeper radii in 5½, 6 and 6½, and the flatter radii in 6, 6½ and 7. At most, one additional smaller lens would be required for the very steep cornea. As previously described, the lens prior to the one which resulted

in a central fluorescein pool would clinically measure the optical dome.

It is not necessary that those engaged in clinical practice resort to this procedure. We believe that if lenses were made just the size of the optic cap of the cornea that they would be almost impossible to handle in addition to the many other problems which would be encountered. We also believe that the larger the lens the greater the ease in handling and the greater the reduction in visual disturbances such as the flare factor. In addition, we know that the usual action of the lids are to pull the lens up. Taking advantage of this knowledge and prior research we propose three principles that should be kept in mind. These are as follows: (1) (a) The steeper the cornea the smaller the optic cap or regular zone. (b) The flatter the cornea the larger the optic cap or regular zone. (2) (a) The steeper the cornea the smaller the visible iris diameter. (b) The flatter the cornea the larger the visible iris diameter. (3) As the cornea flattens the peripheral flattening becomes greater. In other words, there is less difference between the corneal apex and its periphery in a steep cornea than in a flat cornea.

The writer has concluded that the lens construction should be as follows:

1. From 7.2 mm. to 7.55 mm. central radius, the peripheral radii should be .4 mm. flatter in the secondary and .5 mm. flatter than the secondary in the tertiary. The sizes of the zones of the lenses in this range would be: (a) Central zone 6.0 mm. (b) Secondary zone $1\frac{3}{4}$ mm. + $1\frac{3}{4}$ mm. (c) Tertiary zone $\frac{1}{2}$ + $\frac{1}{2}$ mm.

2. From 7.6 mm. central radius to 8.0 mm. central radius, the secondary radius would be .5 mm. flatter and the tertiary .6 mm. flatter than the secondary. The sizes of the zones of the lenses in this range would be: (a) Central zone 6.5 mm. (b) Secondary zone 1.6 mm. + 1.6 mm. (c) Tertiary zone $\frac{1}{2}$ + $\frac{1}{2}$ mm.

3. From 8.05 mm. to 8.25 mm. central radius, the secondary radius would be .6 mm. flatter and the tertiary .6 mm. flatter than the secondary. The sizes of the zones would be: (a) Central zone 7.0 mm. (b) Secondary zone 1.35 + 1.35 mm. (c) Tertiary zone $\frac{1}{2}$ + $\frac{1}{2}$ mm.

4. From 8.25 mm. and up the secondary radius would be .7 mm. flatter and the tertiary .7 mm. flatter than the secondary. The zone sizes with the exception of the extremely flat lenses would be the same as group 3. The construction of these lenses is based upon an analysis of 632 corneae.

It must be borne in mind, however, that this series of lenses is designed for diagnostic purposes only and not for direct prescribing. It so happens that, in so far as the writer's practice is concerned, better

than 50% of patients can be directly prescribed for from this series of lenses—double and triple radii. In other words, the lenses are placed on the cornea, and a clinical analysis made. The prescribing is done from that analysis. As one gains experience with the Contour principle he may find it advantageous, in so far as his practice is concerned, to vary the control lenses somewhat. This is no different from the manner in which practically every practitioner slightly varies his refractive diagnostic tests from textbook procedure.

The lenses used by the writer are designed to enable the optometrist to judge the clinical patterns with and without fluorescein. The lenses are designed in such a way that in the majority of cases the optical zone diameter of the lens will be exact (from a prescribing point of view) or larger. The peripheral flattening is designed so that it will be the proper amount or on the steeper side.

The desired clinical picture, in keeping with necessary prerequisites to prevent corneal changes, is a lens which rests centrally on the cornea or rides up slightly, but never encroaches on the superior limbus, with a central bearing surface of about $\frac{2}{3}$ of the lens diameter in double and $\frac{1}{2}$ in triple radius lenses with complete peripheral clearance. If the optical zone of the lens is too large a dark ring will be created surrounding the corneal regular zone. In addition, there will be a central fluorescein pool in spite of the fact that the lens radius, in its center, conforms with the corneal radius. If a lens is prescribed in this manner it will usually result in edema of the cornea and an increase in refractive myopia. In addition, it will result in tight symptoms and a sealing off of the corneal apex eventually causing corneal exhaustion. A lens having too small an optical zone and/or too flat a secondary radius will ride high on the cornea and encroach on the superior limbus. The usual result is a flattening of the cornea between the corneal apex and superior limbus resulting in a hyperopic spectacle blur. Frequently, this is sometimes preceeded by a myopic blur resulting from friction and pressure. The friction and pressure first causes edema of the corneal tissues. This soon subsides and a reversal occurs. If this condition is permitted to exist the pressure on the limbal vessels sooner or later results in corneal exhaustion.

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OF DRUMS AND CHICKENS

There is a strange pendulum in human affairs that swings from success to excess. If a little works, and a moderate amount even better, we go all out until we run it into the ground. After a long period of practically no public relations in optometry we discovered its value. Now there seems to be a feverish attempt to make everything we do into a news story. Beat the drums!

The Orinda Vision Study has now been published in book form under the title *Vision Screening for Elementary Schools: The Orinda Study* by Blum, Peters and Bettman. As one of the authors I feel a little like a mother hen who has been sitting on a nest of eggs. Its been a long and arduous task, but the chicks are about to hatch. I have been exceedingly careful not to step on any of the eggs. Perhaps, like the mother hen, I feel over-protective toward the chicks. Beating drums may scare off some of the most valuable chicks and the noise may frighten some to death.

This study is truly a cooperative enterprise. Public health officials, education officials, leading ophthalmologists, optometrists, nurses, statisticians, teachers, parents all have worked hard and long to make this a truly comprehensive study. Being realistic and considering the political climate of organized medicine, some of these people have demonstrated considerable courage in participating as they have. They have taken a calculated risk in their sincere desire to help children with vision problems. For this we should be extremely grateful. We should do nothing that might increase the possibility of reprisal against those who have worked so well.

This is a cooperative study—not an optometric study. We have much of interest and concern here, but it is not ours alone. If our public relations or publicity efforts make capital of this so that it looks like an optometric study, we will have lost much of what we have worked so hard to gain.

This study does not need resolutions passed at conventions, it does not need the beating of the drums. It is a scientific effort that can stand on its own feet. It is already attracting more attention than could be obtained by any publicity campaign. Dr. Blum reported it to the American Public Health Association meeting in St. Louis and it will appear in their journal. I have reported it to the American Academy of Optometry in Boston, it will appear in this journal also. Together we reported it to the California Optometric Association. I reported it to the California Educational Research Association in Sacramento in March. The word is getting around. Best of all is that we are being invited to make these presentations, we are not seeking a soap box.

The University of California Press is preparing news releases to four hundred newspapers all over the nation. Review copies of the book will be sent to every major journal in related fields. There is much interest. The chances are you will be asked to discuss this by your local health and education officials. I hope you will be prepared to participate in conservative, dignified, knowledgeable conferences on this subject in your own community.

Finally, please do not beat the drum. The chicks are tender. Let them grow quietly and securely. I have no doubt that you will be proud of them.

HENRY B. PETERS, M.A., O.D.

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SPECIAL REPORTS

TRUTH, FALSEHOOD, AND MEDICAL ETHICS*

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In a special edition of the Journal of the American Medical Association[1] the Judicial Council of the House of Delegates discusses the 1957 code and makes special reference to section three. In this report, the following statement appears: "At no time have optometrists been officially declared sectarian or cult practitioners." This statement is of course literally true. The implication, however, is that optometry may well be a sectarian or cult practice, and that all that is lacking is for it to be "officially declared" such. "Half a fact is a whole falsehood," said Magoon.

It is the author's purpose in the present report to consider the optometric profession in the light of the statement by the Judicial Council. It may be stated at the outset that optometry, like other professions, has a few cultists. It is grossly unfair, however, to judge an entire profession by the few who are irregular and unorthodox, and certainly nothing in the statement of the Judicial Council implies that the reference is to a few optometrists. How, then, may the statement be interpreted?

If the Judicial Council has in all sincerity charged optometry with unorthodoxy then it should not be difficult for the Council to point out that part of the optometrist's training which is irregular or in any way unsupported by a firm scientific basis. Can it be the courses in anatomy, physiology, and physiological chemistry that are suspect? Hardly, for there is nothing unorthodox or unscientific about these courses, which are identical in substance if not in quantity with those same courses as taught in medical schools. Is there anything irregular or unsound about the courses in general histology and bacteriology? The courses in neural anatomy, ocular anatomy, and ocular histology in the optometric curricula of our schools are excellent in caliber, as are also the courses in ocular pathology and ocular histopathology. It should

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not cause any surprise that all the textbooks used in the courses so far mentioned are written by physicians or teachers at medical colleges. So far then, we can note nothing in the optometrist's training that is unorthodox or unscientific.

The courses in psychology which optometrists study follow standard patterns and emphasize perception and learning. There is little or no room for deviation here. Mathematics is taught only in review in order to provide a firm basis for the study of physical and geometrical optics. The days of Galileo are far behind us now, and there is little danger of excommunication for believing the teachings of basic mathematical sciences. Physiological optics is stressed in the various schools of optometry to such an extent that the quality of the instruction in this subject is unequalled anywhere else in the world, even in the medical schools. In case courses in this subject be thought unorthodox or unscientific, it may be well to point out that we abide very much by the teachings of the great physiologist and physicist, von Helmholtz, by the optical science of Kepler, Thomas Young, Gullstrand, Tscherning, Gauss and Listing, by the work of Purkinje and Scheiner, and by that of Aubert, Abney, Fincham and other scientists, not all of whom were or are in the medical fold. There is certainly no room for a charge of being unorthodox or unscientific in respect to physiological optics.

What of the courses in "Optometry"? Here we refer to that which in its essence is the art of correcting by optical means the refractive errors of the eye. Refractive procedures are simply applied physiological optics, the techniques of which were taught by optometrists to the early ophthalmologists in Philadelphia[2] at a time when the medical eye men were losing their prejudice against the correction of visual defects by means of spectacles. The field of refraction was possessed almost exclusively by optometry until about 70 years ago, although the title "optometrist" was not then in general use. If the science of refraction is sectarian or cultist, it is plainly evident that medicine itself wishes to become partly sectarian and cultist, also.

If, however, it is not in the realm of refraction to which the charge sectarian and cultist is levelled, then where else can it be? "Visual Fields" is an important subject in the curriculum of optometry. It is a course in which perimetry is taught as applied to the charting of visual field defects in the seeking out of general neurological and systemic diseases. The textbooks used are written by medical men and the teachings are followed rigidly. Optometrical mechanics as taught to optometrists is largely the art of best adapting lenses to the face by means of frames or mountings.

The art and science of refractive examination, which is optometry's chief clinical interest, can hardly be considered a sectarian or cultist activity. If there *is* anything cultist about the prescribing of spectacles, it may perhaps be found in the offices of those few medical eye men who insist with great vehemence that without "drops" refracting cannot be done. It is ironical that optometric refractionists who are not allowed to use the "magic" drops are accused of being cultists.

It may be deemed unethical for the Judicial Council even to point out what it is which is considered cultist in optometric training or practice. Whatever it is which the Council has in mind cannot be a trivial matter. On the contrary, it must indeed be very important, or why would the Council have gone out of its way to point out that, "At no time have optometrists been officially declared sectarian or cult pratitioners"? The statement is in fact a very mean innuendo of which medicine should be ashamed, and it behooves the rank and file of physicians to disassociate themselves from such views expressed by the Judicial Council. Competition is healthy, but slurring the name of a rival group is quite another matter. "Every violation of truth," says Emerson, "is a stab at the health of human society." On the part of official medicine, it is most unseemly. This wilful and cruel misrepresentation of optometry to physicians and the public must necessarily hurt not only optometry but the public as well and eventually medicine, itself.

Perhaps, I have been too hasty in throwing back the charge of cultism to official medicine for elucidation, for I have overlooked visual training. Optometry utilizes visual training for bringing about greater visual efficiency of the eyes in conjunction with proper correction by spectacles. Also visual training is used in some cases as an alternative to spectacles, and sometimes even as an alternative to surgery in squint cases, and sometimes in the post-operative treatment of squint.

The basic principles of visual training date back to about 1850 and the work of the French ophthalmologist, duBois-Reymond, whose work was further elaborated by Javal before the end of the 19th century. In England, Priestley Smith (1896) took up the educative treatment of squint and introduced his "fusion tubes." Claud Worth, in London, initiated the systematized treatment of squint in children and started the first orthoptic clinic at Moorfields Hospital. Cantonnet and Filliozat added to the honored work of these great men, but comparatively little new has since been added except in the field of instrumentation. The theory of anomalous correspondence, so important in orthoptics, is expounded fully by the great English ophthalmologist, Sir Stewart

Duke-Elder. At the London Refraction Hospital, maintained by British optometrists, much important work in this field has been contributed by Margaret Dobson, M.D. Surely, there is little about the origin of visual training in Europe, or the present practice of it anywhere in the world, that suggests cultism. Although the attitude of medicine in the United States towards any kind of visual training is indifferent if not disparaging, orthoptics is recommended by many ophthalmogists, particularly in metropolitan areas.

It is significant that, a few months ago, the British Parliament conferred official recognition on the optometrists of the United Kingdom. In many respects, the British move slowly but surely, and I am quite sure that there is nothing about the recent honor that savors of a belated acknowledgment of cultist practitioners. Rather it is a formal recognition of true professional service carried on through two world wars and several decades of doubtful peace: a professional service that is second only to that of medicine itself in importance. So important is this service, that medicine in England has undertaken to provide for certain aspects of the clinical training of optometry undergraduates in spite of the fact that optometry as a profession still remains largely free and independent.

How different is the picture of inter-professional relationship in the United States at this time. Resolution No. 77 of the 1957 "Principles of Medical Ethics," states that "it is unethical for any medical doctor to teach in any school or college of optometry, etc." In an earlier paper,[3] I dealt with the fallacy and foolishness of such "ethics." In discussing the resolutions of the Judicial Council, the A.M.A.[1] arrives at the conclusion that, "The House (of Delegates) has reaffirmed that it is a futile gesture to consult on a professional level with one who does not possess the same knowledge, training, experience and ideals as the doctor of medicine."

Let us examine these words closely. "To consult" implies "seeking the advice of," at least, that is the primary meaning of the term. Now there is surely no optometrist who expects an ophthalmologist or physician to seek his advice concerning a patient whom the optometrist wishes to refer to him. It is the optometrist who may wish to be advised, although usually, he simply wishes to hand over the responsibility for medical care and to receive from the medical man the politeness and courtesy which is rightfully expected. Thus the A.M.A. has clearly reversed the facts of the usual optometric-ophthalmological collaboration and has used the twist to emphasize the "futile gesture to consult on a professional level" with the optometrist. Obviously, this is just

so much political gobble-de-gok! "There are two peculiarities inherent in errors," says Blaise Pascal, the French mathematician and philosopher, "an impiety that renders them horrible, and an impertinence which renders them ridiculous." The ridiculousness of this falsehood is further shown by Dean Lawrence Fitch[4] who points out that on the basis of "the same knowledge, training and experience," it would be just as rational to forbid consultation between medical specialists engaged in the different specialties, or between specialists and general practitioners.

"Many years ago, there lived an Emperor who was so fond of new clothes that he spent all his money upon dress and finery." Thus, commences a children's story in a book compiled by Margaret Dobson, M.D., of London. The book[5] provides for special techniques in the visual training of children suffering from amblyopia. This Emperor, on the occasion of a grand procession, was prevailed upon to wear no clothes except the "magic" garments which his unscrupulous tailors and advisers had convinced him would shield his person from the eyes of all except the most stupid and unworthy. I do not think, however, that I would have been impressed by the story, had it not been that it was a child who cried out, "Why, he has got nothing on!" and thus put to shame the Emperor, the courtiers and the crowds of adult people.

Is there not a parallel here reminding us of the simple open-mindedness of children and the fearful confused thinking of their elders? The child's mind sees through the web of pretence, prejudice and transparent irrationality in which adults so often seek to hide themselves. In the story of "The Emperor's New Clothes" it was a child who could not see the "most beautiful cloth imaginable," who could see only the Emperor in all his nakedness. This child must have looked around him only long enough to study with amazement and incredulity the faces of his elders, before making that "historic" exclamation which instantly ended the ridiculous public exhibition of imperial folly. Are there no general medical practitioners, not too bogged down in "ethics," who have retained sufficient child-like simplicity to differentiate between the ethics of Hippocrates and its present day counterfeit used mainly to fight age-old feuds?

The A.M.A. would have physicians believe that every one of its members is free to "determine the propriety of his conduct," for the statement is made that "these principles are not laws but standards." This is an untruth. The same "ethic" used to club optometrists is also used to club physicians who dare to challenge the propriety of A.M.A. pronouncements. It is now a matter of history that a prominent faculty member withdrew from an optometry college because he feared inevitable

ostracism if he continued his affiliation. Again, owing to the passing of a highly esteemed professor who for many years taught pathology, an optometric clinic is now being denied the advantage of didactic first hand teaching in ocular pathology with the actual cases available right there.

How different, again, is this situation to that which will soon prevail in England where medical men will not merely aid in the teaching of optometrists, but will also open up their own halls for this purpose. "The most striking contradiction of our civilization," says Stefansson, "is the fundamental reverence for truth which we profess, and the thoroughgoing disregard for it which we practice." In the United States at this time, we certainly have an example of this in regard to precept and practice as applied to self-determination of propriety among the members of the A.M.A.

There is one other aspect of British optometric practice which deserves mention here. As is generally known, the ophthalmic opticians in England have been using mydriatics and cycloplegics since about 1920. I, myself, in practice over there, found little advantage in the use of cycloplegics for the control of accommodation, but I did find that the use of a mydriatic was in very many cases invaluable. When, about ten years ago, the National Health Service was inaugurated, the ophthalmic opticians continued their role of providing eye examination and refraction for all but a relatively small proportion of the British public, even though these practitioners still functioned as members of a non-registered profession officially non-existent. Early in 1956, in a letter from the Secretary of The British Optical Association, I was informed that about 25 million people had secured refractions by ophthalmic opticians under the National health scheme. It was not possible to know the proportion of cases in which a mydriatic had been used to facilitate examination of the fundus, but since the majority of ophthalmic patients are over 40 years of age, and since in these cases examination of the fundus is usually facilitated by dilation of the pupil, a conservative estimate would say that a mydriatic was used in several million cases. The secretary informed me that he could not recall a single reported instance of harmful effects from the use of mydriatics and cycloplegics by the ophthalmic opticians.

I may safely assume that no basic difference exists between the eyes of the British people and those of the U. S. citizens. I may further assume, therefore, that the use of mydriatics is a perfectly safe procedure. This fact is substantiated by their use by ophthalmologists in this country, very frequently instilled routinely by nurses or office girls before

examination of the eyes by the ophthalmologist. In my opinion the U. S. optometrists have quite a superior training to that which has been obtained by the ophthalmic opticians of England up to this time. Why is it then, that U. S. optometrists are so resolutely resisted in their efforts to have similar privileges to those of the ophthalmic opticians of England? The real reason cannot be that the use of mydriatics involve excessive risks to the patient. Also, the charge cannot be fairly made that optometrists have inadequate knowledge and training in the use of such agents, for even if such a charge could be substantiated, it would be a simple matter to remedy the situation to the inestimable benefit of all concerned. But, alas, such a gesture on the part of medicine would be "unethical." However, on such grounds, there is no need of medical aid to optometrists. I do not think that optometrists need outside help in the matter of the proper use of mydriatics, local anesthetics, fluorescein and wetting agents. The real reason for medical opposition to the use of these aids has yet to be stated.

There is good reason to believe that if the privilege of using certain eye drops was granted, optometrists would use such privilege as the basis for securing almost unlimited privileges in the use of these preparations. Thus, they would begin to invade the field of ophthalmology, short of actual surgery. If ophthalmology entertains any such fear, then I want to say that I can personally understand its view. However, there is one unassailable principle to be borne in mind, i.e., that fear of the future is an inadequate excuse for not doing now what is known to be the right and proper thing. As all of us know, such a principle is extremely hard to live up to, but try we must. It is, therefore, unethical for official medicine to frustrate optometry's efforts in securing any of the tools which the profession needs, while it is shackled by restrictions simply because, if freed of these restrictions, it might ask for more privileges.

However, I think that it is time for optometry to declare most emphatically its reasonable aims and to reassure medicine that freedom to use all reasonable means of diagnosis in the interests of proper referral is quite compatible with the role of optometry as basically defined by the laws of most states. Optometry must be willing to draw the line somewhere between the activities of optometry and those of ophthalmology. Medicine has every right to expect this. A settlement along these lines would be infinitely better than the chaotic situation which prevails now and may otherwise prevail for decades yet to come. It would, indeed, be vastly better for optometry as a learned profession, going forward with ophthalmology, rather than opposed to it, in our

private offices, in factories and great commercial concerns, in the schools, in the union clinics, in the armed forces, and even in the hospitals, properly sharing the responsibilities. This is a reasonable and honorable ambition. Indeed, it is a goal which should already have been reached and enjoyed. But it does behoove optometry to examine itself honestly and sincerely and to acknowledge openly a firm conviction that its aim is basically optometric and not ophthalmological.

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PROBLEMS OF VISION IN AVIATION*

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In flight today the problems of vision differ from those in the past not only because of the better performance of the machine, but also because of the differences in flying technique. Thus today if there is less interest in depth perception it may be because it is becoming possible to land an aircraft entirely on instruments, and without looking outside to judge the height above ground at the final flare out just before touch down. With the great increase in numbers of instruments required in an aircraft, the problems of instrument presentation require for their solution, the skills and knowledge of "human engineering" and consequently a considerable research effort has to be directed towards finding out how a pilot scans his various instrument dials and how much time he spends on each one.

*Read before the annual meeting of the American Academy of Optometry, Boston, Massachusetts, December 14, 1958. For publication in the June, 1959, issue of the AMERICAN JOURNAL OF OPTOMETRY AND ARCHIVES OF AMERICAN ACADEMY OF OPTOMETRY.

†Ph.D., M.B., Ch.B. Squadron Leader, Royal Air Force.

Yet, although the accent may appear to be upon vision within the cockpit or aircraft cabin, the ability of the pilot to use his eyes in searching the sky outside the aircraft is still regarded as most important not only by military but also by the pilots of civil airlines.

The continued importance of visual search of the sky is more of a problem today, because not only is less time available from seeing a target to reacting to it, but also the scene itself which the pilot surveys, is one in which it is more difficult for him to see his target.

The high altitude sky in which more and more pilots have to fly, is characterised by the absence of clouds or other visible detail. Since there are specific problems associated with this type of environment, I have called it an empty visual field: that is, one which may or may not be bright but in which there is no detail visible to the eye.

The empty visual field is characteristic of the visual scene above the tropopause (about 35,000 feet) but it can still be encountered at lower altitudes as a clear blue sky or as mist or fog.

With increasing height above the surface of the earth the sky becomes progressively darker, its luminance bearing a direct relationship to the atmospheric pressure, but even when a height is attained at which the stars will be visible, in the daytime sky, it is doubtful whether a pilot would be capable of seeing them because he will almost certainly have within his immediate visual field some objects illuminated by direct sunlight if not direct sunlight itself. The high contrast between the bright area and the dark sky would probably prevent him from becoming sufficiently adapted to the lower luminance to see the stars in it. This effect could be easily overcome by spending some minutes away from the sunlit areas. This problem is like that of looking out of a window of an illuminated room at night. It is not possible to see the stars of the night sky unless one goes close to the window to remove specular reflections and to keep the higher intensity light out of the eyes.

And so it seems that the visual field observed by the pilot flying outside the earth's atmosphere may also be empty with the possible exception of some of the brighter stars and with the exception of the visual field seen when looking towards the surface of the earth.

There are a number of interesting problems associated with the empty visual field which are of both a physiological and of a psychological nature. To the physiologist, the most interesting is certainly that associated with accommodation.

It seems that when the visual field is devoid of visible detail, the emmetropic eye is unable to relax to its punctum remotum at infinity.

Accommodation is usually accepted as being fully relaxed when the eye is focussed at the far point, but these findings would appear to indicate that the relaxed or "resting" position of the accommodation mechanism is for an intermediate position. Only the lens and its suspensory ligaments would be fully relaxed when the eye was accommodated at the far point and the resting position of the ciliary muscles might be associated with one dioptre of accommodation. On a teleological basis, it is reasonable that the resting position of accommodation should be not for infinity, but for a closer distance such as arm's length.

The experiment's carried out have been reported in detail. Briefly, two techniques were employed, one subjective, which had the advantage of ease and speed of application, and one objective technique carried out in conjunction with Dr. F. W. Campbell. In the subjective technique, the visual field was rendered empty by fogging out the background with a 4D lens. At the focal point of this lens, namely at optical infinity, was a target plate with black dots so small that they were visible only when they were in focus. By moving the plate carrier back and forward, it was thus possible to determine after calibration the amount of accommodation from the position of the plate when the dots became visible. One could thus "seek out" the amount of accommodation whilst the eye was looking at an empty visual field and without introducing into the visual field an accommodation stimulus.

The objective technique consisted in positioning a double light source so that its Purkinje Sanson image reflected off the anterior surface of the crystalline lens could be photographed. On the photograph, measurement of the separation of the two lights indicated the amount of curvature of the anterior surface of the lens, and from this it was possible after calibration to determine the amount of accommodation again whilst the subject looked at an empty visual field and again as in the subjective technique without presenting the subject with any visible detail. This technique was not always employed because accurate fixation had to be maintained in order to see the reflection off the lens, and this rigid eye fixation was not compatible with the search which would be taking place in practice when looking out from an aircraft cabin.

The results obtained by these techniques showed that in the presence of an empty visual field, subjects were unable to relax accommodation to the far point. Accommodation was shown to be in a state of constant activity, fluctuating about a level of 0.5 to 2 dioptres, and sometimes approaching the far point but never quite reaching it.

When a cycloplegic was employed, this involuntary accommodation disappeared and the eye remained focussed at the far point, suggesting thereby that this effect was indeed one of accommodation. Pupil size in all these experiments was controlled by employing an artificial pupil.

If a stimulus, presented at the far point, was accurately focussed and then removed, the eyes remained for a short time focussed where the stimulus had been, but then after some seconds involuntary accommodation reappeared. If one considers the emmetrope who might have been employing collimated stimulus to overcome his involuntary accommodation, the improvement which he had derived from this procedure was soon lost.

An experiment was therefore carried out to measure the rate at which accommodation assumed its resting level: first, after loss of a stimulus at the far point, then after loss of a stimulus at the near point. Since the resting level of accommodation fluctuates, it is not possible to give rigid values, but in general the results showed that after losing sight of a near as well as of a distant stimulus, it took some 60 seconds for accommodation to reach its resting level.

It was obvious that a stimulus at the far point would be more effective in overcoming involuntary accommodation if it was seen foveally, and that its usefulness would decrease as it was seen more and more in the periphery of the field of view. Accordingly, a series of experiments was carried out to determine the quantitative effect of the angular distance between stimulus and fovea. Since one had to preserve an empty visual field the simplest method seemed to be to have a black circle inscribed on a glass plate, and this plate placed at the far point. The subject then fixated what he judged to be the centre of the circle, obtaining thereby a stimulus at the far point at a known angular distance from the fovea, whilst maintaining foveally an empty visual field.

The fact that an emmetrope searching a cloudless sky might be accommodating involuntarily to the extent of one dioptre, does not mean that he cannot see anything beyond one metre, because fortunately depth of focus associated with his pupil size will compensate to some extent. From the practical aspect again it was required to know by how much involuntary accommodation would reduce the pick up range of a distant target. A group of 63 subjects was tested after the apparatus had been modified to present them with collimated targets of various sizes, with and without a collimated fixation pattern beside them.

The results are presented in Table I and it is evident that with no

TABLE I.

Distance at which the collimated target is detected with and without the help of a superimposed collimated fixation pattern.

	Mean	*Standard deviation*	*Range*
No stimulus distance	9.9	4.0	4.5—18.0
With stimulus distance	19.0	2.1	12.0—24.0

visible detail to help them, subjects only detected the target when it was twice the size at which it was visible with the help of the fixation pattern. In terms of pick up range, the involuntary accommodation associated with the empty visual field reduced the pick up range by half. As a counter check on the amount of accommodation that this reduction of acuity represented, one subject was examined after instillation of a cycloplegic to paralyse accommodation. The different levels of accommodation were simulated by placing before the eye, lenses of various powers. The previous experiment of increasing target size was then repeated. It was noted that a reduction of acuity by half is associated either with a refractive error of one dioptre beyond optical infinity, or with a myopia of about 0.75 dioptres.

To summarize, it has been found that the absence of detail at infinity in an empty visual field renders it impossible to adjust the eyes with any certainty for a focus at infinity. When no definite object is being fixated, as when one is searching in an empty visual field, the point at which the eyes are focussed is constantly changing. In general, however, the point of focus may fluctuate about a given level, and in the case of a long sighted individual the point of average focus may be beyond optical infinity. He may thus be focussing rays of light which are converging towards his eye. The low hypermetrope may have an average point of focus about optical infinity. In the emmetropic eye, it is not possible to focus beyond optical infinity, and when this eye views an empty visual field, the average focus is nearer than infinity so that the emmetropic eye becomes under these conditions virtually myopic. Likewise the myope becomes even more myopic.

It must be emphasised that the accommodation mechanism is in a state of constant activity and is seldom stationary at any one level, particularly when an empty visual field is being observed. Realising that there is difficulty in focussing at infinity, an individual may make a voluntary effort to look in the distance. This effort can never deliberately cause the eye to relax to infinity and, on the other hand, it frequently causes accommodation to increase so that eventually the point of focus may be much nearer than it would have been if no voluntary effort had been made.

It is thus not possible to state that a given individual whose eye has a certain refraction will be focussed at a certain distance during search in an empty visual field. One can merely state in broad terms that, under the best conditions possible, the slightly far sighted subject may have most advantage, since he may be focussed at infinity.

Thus, when searching in an empty visual field, it seems to be largely a matter of luck whether an individual focusses his eyes for infinity or not. He can, with training, learn not to make the voluntary increase in accommodation and to allow his eyes to relax. He cannot, however, without a stimulus at infinity, overcome the empty field myopia which makes him focus one to two metres away instead of an infinity.

It is clear that some aid is necessary to enable subjects to focus optical infinity which as far as the eye is concerned with a pupil size of 2 or 3 mm. may be regarded as being about 30 feet from the eye. Looking at another aircraft will therefore automatically make the eye focus at infinity. Again, however, one must remember the hypermetrope for he, looking at an object 30 feet away, may voluntarily throw it out of focus so that his eyes focus a point beyond optical infinity. Thereby he may lose the advantage gained by the presentation of the target at infinity, and be at the same disadvantage as the emmetrope or myope.

It is consequently necessary to learn to use the eyes when searching in an empty visual field, either with the help of some aid, such as an optical device which projects a pattern at infinity, or when using an object in the foreground such as a wing tip, or another aircraft. Any effort which may be made by the subject succeeds merely in causing his point of focus to come much nearer than the average resting position he could achieve when looking at an empty visual field. Thus, when one searches in an empty sky for another aircraft, if an effort is made to overcome the appreciable difficulty in focussing, one frequently finds that one is suddenly focussed on the small specks of dirt on the windscreen, apparently because the point of focus has gradually approached as the efforts were being made to relax accommodation further.

Associated with the empty visual field, however, are a group of problems which belong rather to the realm of psychology. When movement being observed is of small angular size, its perception depends upon there being a fixed background pattern against which it will be detected. In the absence of such a background the perception of movement is no longer possible with any certainty.

When a cat is about to jump it moves its head up and down

presumably in an effort to judge distance by relative displacement, between the target and its background. In the air, judgments of distance are similarly more accurate when they are based on parallactic displacement but, again, as with distance perception if there is no background detail, parallactic clues can no longer be employed and the judgment of distance becomes erratic. (We are considering, here, distances which are too great to be helped by binocular parallax or convergence clues.)

From the perception of distance, one makes deductions as to the size of an object, and from the perception of movement one makes deductions as to its speed. If the visual field is empty it is evident that these judgments are no longer possible with any accuracy and that the difficult task of search is made more difficult still since one has lost the clue of movement which might have rendered more easily detectable a target at threshold visibility.

BOOK REVIEWS

MY FIFTY YEARS IN OPTOMETRY, VOLUME II, AN AUTOBIOGRAPHY. Albert Fitch, O.D. Published by the Press of the Pennsylvania State College of Optometry, Philadelphia, Pennsylvania. 385 pages. Illustrated. Cloth. $10. 1959.

This book could fittingly be subtitled, "One Man's Fight for Professional Optometry," for here the author continues from his first volume by the same title, his detailed coverage of the struggle that has marked the last five decades in the history of Optometry.

This book follows along very much the same plan as the first volume, using source materials, to a very large degree, and adding his own comments and explanations only as a means of achieving continuity and clarity. In this book, he is broadening the scope of his interest in education. While his correspondence and speeches still emphasize better professional schools and higher educational standards, he turns his attention to the profession itself, and shows through the medium of his various documents, how a more professional attitude on the part of optometrists everywhere is being gained. And, too, there is material included here, designed to educate the general public to the aim and ideals as well as the practices of the professional optometrist.

One of the interesting experiences in reading this book was again meeting—through the medium of their own written words—some old friends who have been active in optometry throughout the years. One catches a glimpse of a familiar personality, through touches of humor,

practicality, stubbornness, friendliness—or even anger, as one reads the letters after the passage of so many years.

Albert Fitch has completed a very tedious and time consuming job in compiling the material for this volume. A man less dedicated would have dispaired of the task of assembling and organizing the abundance of correspondence, news clippings, and reports that have gone into making this book.

Through this unique contribution, Fitch has provided a reference book which definitely has a place in the library of every college of Optometry. And, to the young optometrists who have recently begun to practice, it can be an invaluable help as the author shares with them his vast experiences and gives them the story of the development of their chosen profession, both its educational and legal aspects. It is also an excellent reference for any group preparing professional legislation, because here may be found helps in wording and content of legislation passed by various states—also, a first-hand account of the pitfalls and high points of each bill, and its eventual success or failure.

It would be a well-worthwhile study for groups, or an individual planning promotional work of any kind as it relates to the professional or educational fields. These are the projects dear to the heart of Albert Fitch, and every scrap of material—be it records of a planning meeting, a newspaper report, or criticism of the results—are preserved here for posterity to study and review.

JOHN D. PERRY, JR., O.D.

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A TEXTBOOK OF MEDICINE. Tenth Edition. Edited by Russell L. Cecil, M.D., Sc.D., Cornell University, and Robert F. Loeb, M.D., Sc.D., Columbia University. Published by the W. B. Saunders Company, West Washington Square, Philadelphia. 1,665 pages. 182 Illustrations. Cloth. $16.50. 1959.

The 10th edition of this medical text has just appeared. It has been rewritten during the last four years and without question will find welcome with general medical practitioners as well as many medical specialists. The technical contributors number 166.

This is not an optometric book. The reviewer wishes to point out, however, that the Foreword, *Patient-Physician Communcation*, applies equally well to optometrists and would be excellent reading for every member of the optometric profession. This foreword by Dana W. Atchley, M.D., deals with (1) the need for a sympathetic and discerning case history, (2) proper communication on the emotional

level, (3) proper communication on a cultural level, and (4) on an intellectual level, (5) the need for mutual integrity in communication, and (6) last of all, the value of humor. Here the author stresses that while the best of technical training is, of course, essential, that these values do much to improve the art of medical practice.

On page 1,425 Harold G. Wolff, M.D., professor of neurology at Cornell University, discusses headaches. He says that astigmatism, hypermetropia, anomalies of accommodation, disturbances of the extraocular muscles and also glaucoma are the cause of headaches but that simple myopia does not evoke these pains. In his discussion he calls attention to the fact that the myope, in attempting to improve his vision by contraction of his eye muscles, actually makes vision worse and soon abandons the effort.

Wolff believes that headaches associated with ocular disorders are the result of sustained contraction of the intraocular muscles associated with excessive accommodative effort expended to attain fusion and single binocular vision. The author also points out that electromyograms from the muscles of the neck and scalp reveal muscle contraction. In this vast text the eye and its problems is mentioned by a number of authors in addition to the one quoted.

CAREL C. KOCH, O.D.

EYES, VISUAL ANOMALIES AND THE FUNDAMENTAL READING SKILL. Earl A. Taylor, Director, Reading and Study Skills Center, 15 Washington Place, New York City. 204 pages. 60 illustrations. 30 case reports. 608 references. Board covers, spiral bound. $5.00. 1959.

This publication bridges the gap between eye care and educational difficulties. The author calls attention to the emphasis on improving the present educational system, as well as the need for increased cooperation among the health specialists who attend children and adolescents. He points out the manner in which school programs can be improved. In doing so, Taylor has delineated, in part, optometry's role in diagnosing and treating visual problems related to reading and academic deficiencies.

First, by means of a case history form, called the Functional Readiness Questionnaire, he establishes the symptomatology associated with individuals who need assistance in this area. He then reviews briefly the visual training procedures which have proved effective in developing individuals to the point that they are able to sustain effort at the reading distance, comfortably, for extended periods of time.

This first step in his visual-educational rehabilitation is called "raising the level of Functional Readiness."

A discussion of eye movements in reading is illustrated by eye-movement photographs of subjects representing each type of abnormality reported. In addition, the components of the Fundamental Reading Skill (i.e., the rate of comprehension, the span of recognition, and the number of fixations and regressions made by an individual while reading 100 words) are explained and ways and means of developing this skill are presented. A table of norms for all grades from first to college is included. A college student should read a paragraph of one hundred words, making only 75 fixations (eye stops) and 11 regressions. This results in an average span of recognition of 1.33 words per fixation. A reading rate of 340 words per minute is expected.

A few of the reading graphs which the reviewer found most interesting included: One which demonstrated that readers, who read at the same rate, do not necessarily read with the same degree of efficiency. For example, while two readers may each read at a rate of 421 words per minute, one may make 50 fixations and 2 regressions, while the other makes 90 fixations and 6 regressions.

Another graph illustrates the manner in which one eye overconverges after the individual has read a few lines. The amount of overconvergence is a function of the increase in linear distance between the two traces, one from each eye. Normally these traces are parallel after the first fixation of each line.

The third graph showed the improvement in a student's Fundamental Reading Skill after approximately 34 hours training with the Tach-X (Tachistoscope) and Controlled Reader. The subject improved from 112 fixations with 26 regressions to 46 fixations with no regressions. The comprehension remained constant at 90%. In his chapter, "Visual Difficulties in Terms of Ocular Patterns," Taylor discusses and illustrates reading graphs of individuals with hyperopia, myopia, astigmatism, anisometropia, aniseikonia, aphakia, and nystagmus. There is also a series of graphs demonstrating the reduction in amplitude of nystagmus as visual training proceeded.

A bibliography of 608 references concludes this publication. I recommended that optometrists read this book to improve their understanding of the relationship of office practice procedures to reading and academic problems.

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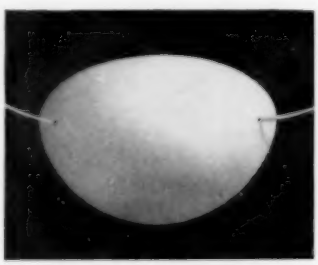

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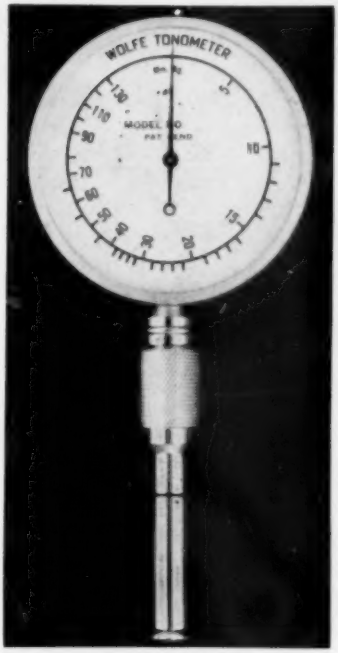

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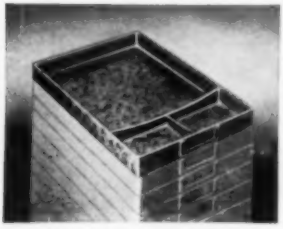

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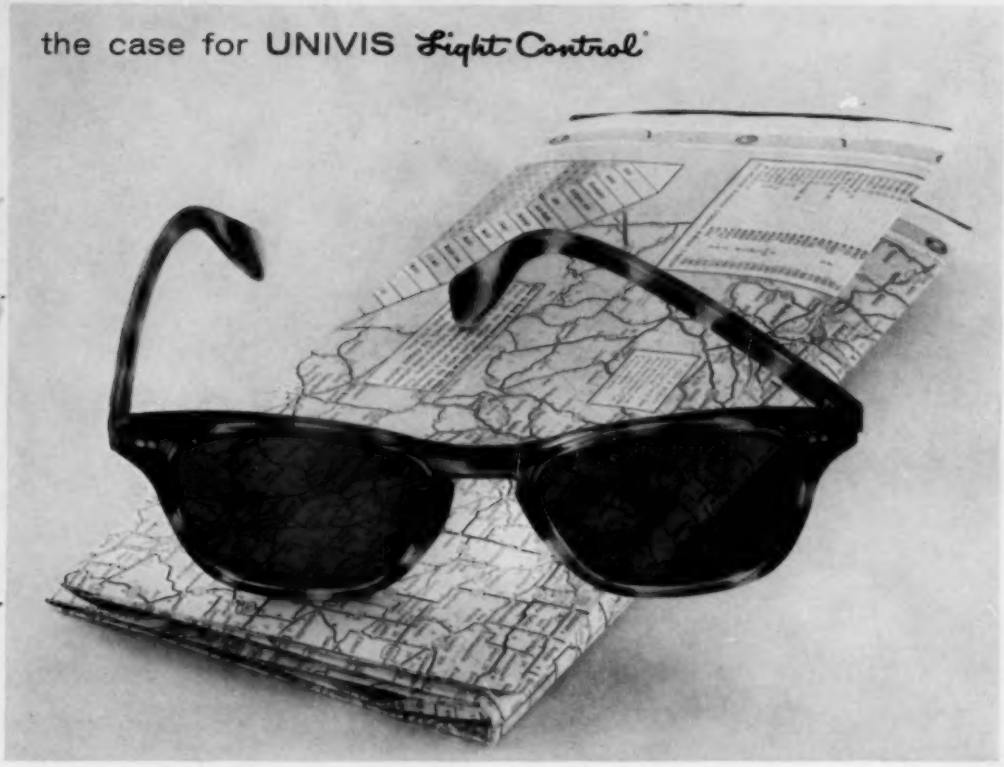

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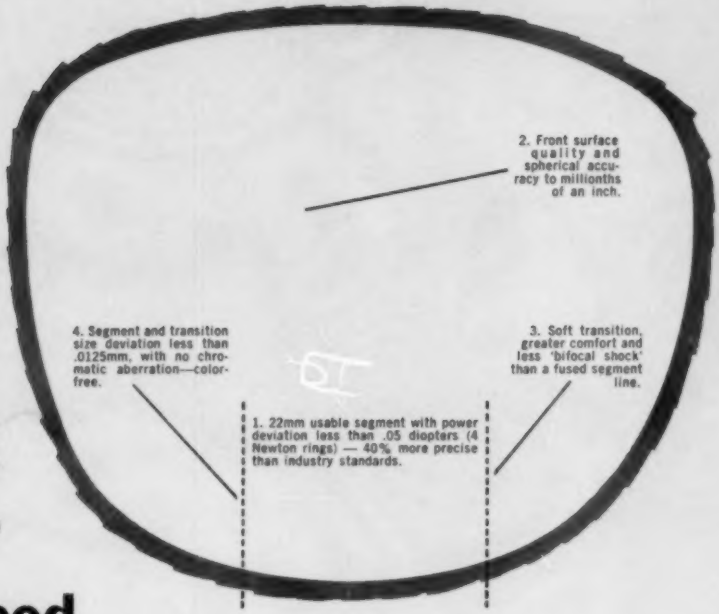
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